DEDICATED TO MAKING A DIFFERENCE

Mobility 2030: Meeting the challenges to sustainability

The Sustainable Mobility Project

Overview 2004

Forewords

Promoting mobility is a key part of our companies' business. We seek to do this in ways that satisfy the widespread desire for affordable and safe transport, reduce the impact transport has on the environment and utilize the most appropriate technologies as they are developed.

We are making progress on these objectives and are reassured that many societies share similar goals. However, the policies adopted to achieve these goals can differ widely and the context in which our companies operate is becoming more complex every year. One of our tasks is to respond to this diversity.

Transport and mobility are now high on many agendas as countries and regions across the world seek to increase mobility and to lessen transport's impact. Our collective view has always been that both these goals are attainable. Four years ago we decided to work together to achieve better understanding of the challenges and options.

The result of this cooperation is *Mobility 2030*. It reflects the collective efforts of more than 200 experts from a broad set of 12 industrial companies who have taken part in the Sustainable Mobility Project's committees and work streams. Normally our companies compete vigorously, so to produce such an in-depth, agreed analysis is a distinct accomplishment.

Our thanks go to the WBCSD for serving as an invaluable catalyst and for providing the platform that facilitated this accomplishment. We also acknowledge with gratitude the many contributions made by outside experts including the Assurance Group.

Mobility 2030 sets out a vision of sustainable mobility and ways to achieve it. The report has developed a framework to connect a diverse set of economic, social and environmental strands; and in identifying the key issues and choices we face it has developed a set of goals to provide focus for future action, and charted a number of pathways as a basis for this. But we clearly recognize that a project like this can only be an introduction to an extraordinarily complex, diverse topic that confronts all societies.

We began with the project's initial study *Mobility 2001* which assessed the worldwide state of mobility and identified the particular challenges to making mobility more sustainable.

Our new report develops this thinking and shows how sustainable mobility might be achieved and how progress towards it could be measured. We have concentrated on road transportation, reflecting our member companies' expertise in this area. What *Mobility 2030* says about fuel and vehicle technologies is a key contribution. Our hope is that other industries and stakeholders will be inspired to undertake their own studies with a similar focus to this report.

As companies operating in a competitive market we can, and do, hold different views about some of the technology choices and timescales. We think that *Mobility 2030* reflects these differences without diminishing its core purpose of identifying and suggesting the most appropriate solutions.

We acknowledge that much remains to be learned, in particular about the best ways to engage societies effectively around sustainable mobility issues. Nevertheless, as companies deeply involved in the provision of transport products and services, we think this project has moved the sustainability agenda forward in ways that can be developed.

We believe that *Mobility 2030* points to new collective initiatives. Yet, much is already happening. On road safety our companies have a number of programs to improve the safety prospect for vehicle occupants and pedestrians in both developed and developing countries. And much is going on in other areas such as the industry partnerships that are now advancing the development of alternative fuels and powertrains, as our companies seek to provide the mobility choices customers ask for while moving to address the issues clearly spelt out in the report. We recognize the focus the report provides on the significant challenges in the developing world.

A clear message from *Mobility 2030* is that if we are to achieve sustainable mobility it will require contributions from every part of society throughout the world. Our companies are committed to making their contribution, and the work of this project will help us to clarify our own role and areas for further collaboration. It is with the hope that your country and your organization will want to build on what is offered here that we pass this study on to you.

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Individual businesses can do much in pursuit of sustainability, but the challenges are far too complex for even the biggest company to tackle by itself. Developing the right framework conditions is critical and can only be done effectively by companies working together throughout the value chain. It also requires broad interactions with stakeholders to achieve a common understanding of how to address the challenges. This is the essence of the WBCSD's Sustainable Mobility Project, the largest member-led sector project ever undertaken by the Council.

When the project started over four years ago, it took on what, in hindsight, can only be described as an immensely ambitious brief: to assess the current state of mobility in all modes of transport in both developed and developing countries and to develop a vision of what sustainable mobility would look like and how to get there. The project members' unbridled enthusiasm was laudable but ran the risk of only scratching the surface. For an in-depth study, they finally decided to take a more focused approach and selected road transportation as the departure point.

The pathway to sustainable mobility is not likely to be a smooth one. The project's first report, *Mobility 2001*, an arm's length snapshot of mobility at the end of the twentieth century, showed just how difficult the journey would be. Nevertheless, I can now say the project has delivered what it promised: an informed and well researched description of what sustainable mobility should look like in various parts of the world, and what is required to implement it. It demonstrates the continuous commitment of the member companies to contribute to a sustainable development.

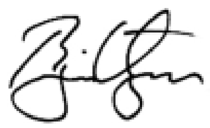
In some areas, the project went further than anything undertaken previously – from modelling challenges to measuring the gap between where we are, and where we want to be. I believe that its biggest achievements are two-fold, first, the sheer volume of knowledge that has been assembled. Over the span of the project, experts have traveled the world from Sao Paulo to Shanghai, from Prague to Cape Town, meeting stakeholders from all parts of society. The group also drew on all available intellectual sources to come up with what is truly a remarkable piece of work.

Secondly, the project fostered unprecedented cooperation among a core group of major companies representing vehicle technologies, fuels and parts suppliers. In total, the group represented over three quarters of the production capacity of motor vehicles globally. The commitment and positive approach of these companies give reason to believe that sustainable mobility, though still distant, will be achieved.

I would like to thank the member companies and the three co-chairs for their vision and strong support, and for making experts available to work on the project. Special thanks also go to my WBCSD colleagues, Per Sandberg, Michael Koss, Tony Spalding, Arve Thorvik, Kristian Pladsen, Peter Histon, John Rae, Claudia Schweizer and Mia Bureau, who backed them up.

I would also like to thank members of the Working Group for their devotion to this project, especially Charles Nicholson for forging the Working Group into an effective team, with all his diplomatic and consensus-building skills, and George Eads whose experience, great clarity of thought, and commitment, as the lead consultant, were decisive in bringing both *Mobility 2001* and *Mobility 2030* to fruition. I am further grateful to Lew Fulton from the International Energy Agency for his important contribution.

And finally, thanks are due to the Assurance Group, under its chair Simon Upton, which paid close attention to the quality and validity of the work from the initial stages of research to the final published findings.



President, WBCSD

contents

I. Introduction

This Overview provides an extended summary of the final report of the World Business Council on Sustainable Development's (WBCSD's) Sustainable Mobility Project (SMP). We launched the SMP in April 2000 to understand better how the needs of society to move freely, gain access, communicate, trade and establish relationships might be improved without sacrificing other essential human or ecological requirements now or in the future.

Each of us is deeply involved in some aspect of mobility. Eight produce transport equipment. Three provide fuels to the transport sector. One is the world's largest producer of tires for road vehicles. Another is a major producer of light metals for the motor vehicle industry. For all our companies, long-run success depends on the future viability of mobility. It is our collective view that the mobility sector will not be healthy over the long term unless mobility is made sustainable.

This is the second major report to be issued by the SMP. The first, *Mobility 2001*, was published in October 2001. *Mobility 2001* assessed the state of worldwide mobility at the end of the 20th century and its sustainability. The principal message of *Mobility 2001* can be summed up in the introduction to the final chapter "World Mobility and the Challenge to its Sustainability":

"Both personal and freight mobility is at an unprecedented level for the great majority of the population in the developed world. However, personal mobility differs significantly by age, income, and location. In contrast, most of the citizens of the developing world suffer either from poor or deteriorating mobility. The central problem is that cities in the developing world are growing and motorizing very rapidly. In order to achieve sustainable mobility by the middle of the 21st century, at least seven mobility-related "grand challenges" will have to be overcome. Moreover, an additional challenge going beyond mobility – the creation of the institutional capability able to tackle such "grand challenges" – will have to be met." (SMP 2001 p.1)

Since publication of *Mobility 2001* the SMP has been assessing how the mobility-related trends identified in that report might evolve over the next several decades, what approaches might be available to influence this evolution in ways that would make mobility more sustainable, and what is required to enable these approaches to succeed.

As a result of this assessment, we have identified seven goals toward which we believe society should strive:

- **Reduce transport-related conventional emissions (carbon monoxide, nitrogen oxides, volatile organic compounds, particulates, and lead) to levels such that they cannot be considered a serious public health concern anywhere in the world.**
- **Limit transport-related greenhouse gas (GHG) emissions to sustainable levels.**
- **Significantly reduce the worldwide number of deaths and serious injuries from road crashes. Efforts to do this are particularly needed in the rapidly motorizing countries of the developing world.**
- **Reduce transport-related noise.**
- **Mitigate transport-related congestion.**
- **Narrow the mobility "divides" that exist today (a) between the average citizen of the world's poorest and the average citizen of the wealthier countries, and (b) between disadvantaged groups and the average citizen within most countries.**
- **Preserve and enhance mobility opportunities available to the general population.**

These goals are directed to society as a whole. We are proposing them as the first step in what we hope will become a continuing dialogue among a broad range of stakeholders. As significant participants in a range of mobility-related activities, SMP member companies must play a part in enabling many of these goals to be achieved. However, none can be achieved solely as a result of the efforts of SMP members. Rather, the effort must be a cooperative one involving private industry, governments, and the public at large.

What convinced us that these goals are necessary? Quite simply, we took a look into the future and were troubled by what we saw.

II. Prospects for mobility and its sustainability if present trends continue

To help us understand what the future might hold, we projected certain key mobility-related trends extending through 2050. In considering these trends, it is important to understand the difference between a "projection" and a "forecast." A projection is a mathematical exercise – a working out of the consequences of particular rates of change and starting conditions. A projection does not inherently require a belief that all of the levels and rates used in its execution are the right ones. A forecast differs from a projection in that it assumes that certain inputs are more likely than others to be right, and so it adds to the projection a sense of likelihood.

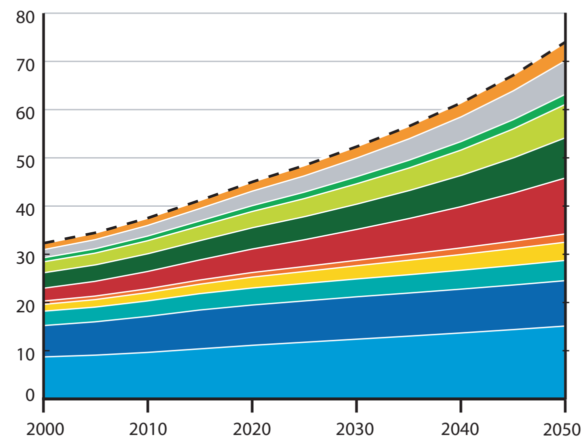
Our projections are based on the assumption that present trends continue. This implies that (a) "mainstream" projections of economic and population growth are realized (b) the general trajectory of technological development and its incorporation into transportation systems and services continues much as it has over the past several decades and (c) policies currently in place continue to be implemented but no major new initiatives are launched.

Clearly, not all present trends are likely to continue. So the projections made should be seen as benchmarks rather than forecasts to be used to measure the impact of change.

The starting point for our projections was the work of the International Energy Agency (IEA). The IEA is an autonomous body established in 1974 within the framework of the OECD to implement an international energy program. It carries out a comprehensive program of energy cooperation among 26 of the OECD's 30 member states. It also publishes a biennial report titled World Energy Outlook (WEO). *(IEA 2002)* In this publication it projects the long-term supply and demand outlook by fuel type and major energy user sector for the world as a whole, for major regions, and within these regions for certain countries. One of the sectors includes projections for transportation.

The level of detail and the timescale used in the WEO transportation projections were insufficient for the needs of this project. So we made a grant to the IEA's Energy Policy and Technology Division to undertake a major expansion of the transportation sector of its Energy Technology Perspectives model. In connection with this expansion, IEA experts and members of the SMP worked together to develop a detailed spreadsheet model of the transportation sector. It was this spreadsheet model that was used to develop quantitative projections of several of the project's sustainable mobility indicators and to help judge the likely direction of several others.

Figure 0.1 Personal transport activity by region



Average Annual Growth Rates	2000-2030	2000-2050
Total	1.6%	1.7%
Africa	1.9%	2.1%
Latin America	2.8%	2.9%
Middle East	1.9%	1.8%
India	2.1%	2.3%
Other Asia	1.7%	1.9%
China	3.0%	3.0%
Eastern Europe	1.6%	1.8%
Former Soviet Union	2.2%	2.0%
OECD Pacific	0.7%	0.7%
OECD Europe	1.0%	0.8%
OECD North America	1.2%	1.1%

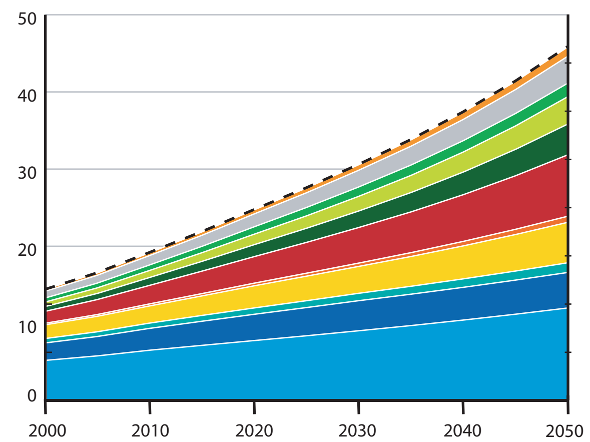
Source: Sustainable Mobility Project calculations.

These projections constitute what we call our "reference case."

In this reference case:

- *Personal and goods transport activity globally grow rapidly* driven primarily by the projected growth in real per capita income. Transport activity growth is especially rapid in countries of the developing world. However, this growth is not sufficient to overcome "mobility opportunity divides" that exist (a) between the average citizen in the poorest countries and the average citizen in developed countries, and (b) within nearly all countries, between the average citizen and certain excluded groups.
- *Already high levels of individual access to personal mobility in most of the developed world increase.* Whether this will also be true for the typical resident of the developing world is more questionable.
- *Further improvements in goods mobility* enable consumers to obtain a greater quantity and variety of goods at lower cost, helping to support economic growth and development.
- *Transport-related conventional emissions (emissions of NOx, VOCs, CO, and particulates) decline sharply in developed countries* over the next decade or two. In urbanized and urbanizing areas of many developing countries they increase over the next few decades before declining.
- *Transport-related conventional GHG emissions grow significantly especially in developing countries.* The energy efficiency of transport vehicles improves, but these improvements are more than offset by a combination of increases in the number of vehicles and in average vehicle utilization.

Figure 0.2 Road and rail freight transport activity by region



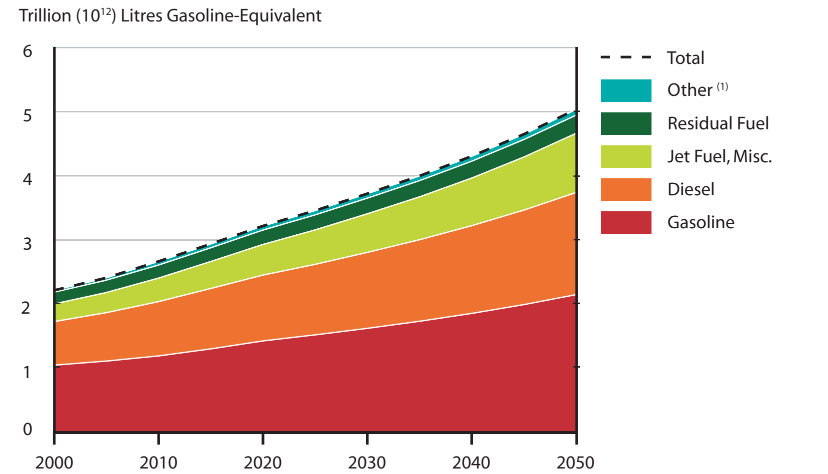
Average Annual Growth Rates	2000-2030	2000-2050
Total	2.5%	2.3%
Africa	3.4%	3.1%
Latin America	3.1%	2.8%
Middle East	2.8%	2.4%
India	4.2%	3.8%
Other Asia	4.1%	3.7%
China	3.7%	3.3%
Eastern Europe	2.7%	2.8%
Former Soviet Union	2.3%	2.2%
OECD Pacific	1.8%	1.6%
OECD Europe	1.9%	1.5%
OECD North America	1.9%	1.7%

Source: Sustainable Mobility Project calculations.

Transport continues to depend overwhelmingly on petroleum-based fuels, so changes in the GHG emissions characteristics of transport fuels have no significant impact on transport-related GHG emissions.

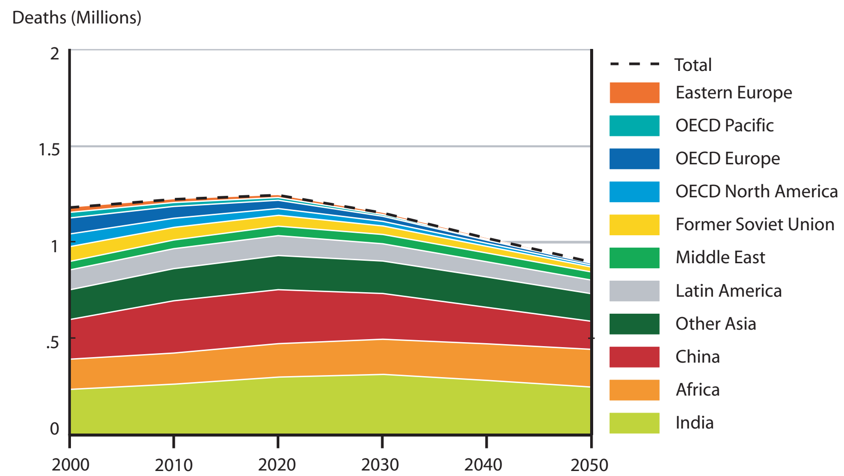
- *Road vehicle-related deaths and serious injuries decline* in OECD countries and some "upper-middle income" developing countries. But they rise for at least the next two decades in many lower-income, rapidly motorizing developing countries.
- *Congestion increases in all (or nearly all) major urbanized areas in both the developed and developing worlds.* Average travel time may not increase proportionally due to offsetting adjustments that individuals and businesses may make in their location choices as well as in other mobility-related decisions. But the reliability of personal and goods mobility will be adversely impacted.
- *Transport-related security remains a serious concern.*
- *Transport-related noise probably does not decrease.*
- *Transport's resource "footprint" grows* as transport-related materials use, land use, and energy use all increase.
- *Personal mobility spending as a share of households' total spending remains roughly constant or declines for households* in most parts of the developed world and for some households in the developing world. In large parts of the developing world the trend in the share of household income devoted to personal mobility is subject to contradictory pressures, making its direction difficult to predict.

Figure 0.3 Worldwide transport-related fuel use - all transport modes



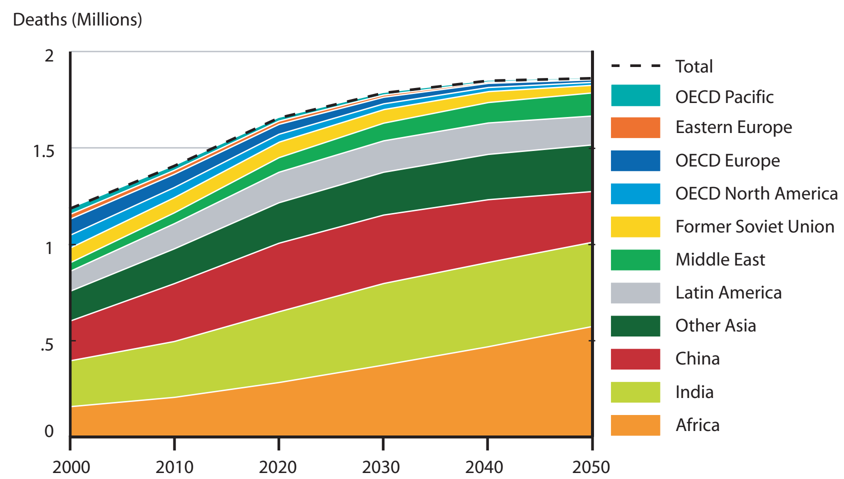
[1] CNG\LPG, Ethanol, Biodiesel, and Hydrogen Source: Sustainable Mobility Project calculations.

Figure 0.4a Total road-related deaths by region - Reference Case #1



Note: Reference Case #1 and Reference case #2 use different assumptions concerning the risk decay factor over time.
Source: Sustainable Mobility Project calculations using data from **Koornstra 2003**

Figure 0.4b Total road-related deaths by region - Reference Case #2



Note: Reference Case #1 and Reference case #2 use different assumptions concerning the risk decay factor over time.
Source: Sustainable Mobility Project calculations using data from **Koornstra 2003**

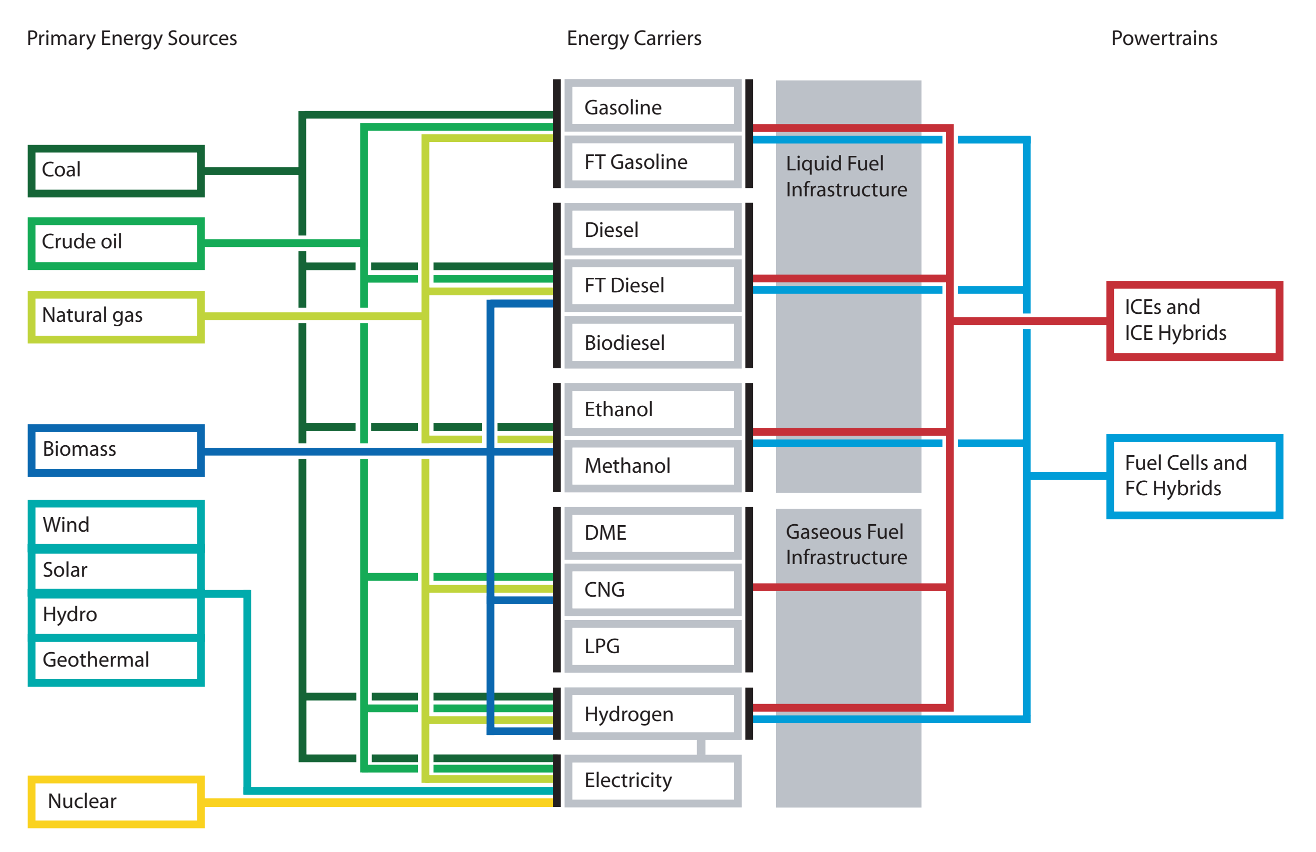
- *Some mobility-related equity concerns grow,* especially those relating to differences in accessibility available to the poorest, the disabled and handicapped, and the elderly. Other equity-related concerns such as the disproportionate exposure of certain groups to transport-related conventional emissions may decline.

Factoring in all these findings, it appears to the SMP that the present system of mobility is not sustainable, nor is it likely to become so if present trends continue. Not all the indicators point to a worsening of the situation. But enough do for the SMP to conclude that societies need to act to alter their direction. This is true, in particular, if mobility is to be made sustainable in the developing world.

III. The potential of vehicle technologies and transport fuels to be "building blocks" of sustainable mobility

What can be done to change this outlook? A wide range of factors impact the sustainability of mobility. However, as suppliers of road vehicle components, road transport vehicles and the fuels that power them, SMP participating companies considered it especially important to explore the potential contribution that road vehicle technologies and fuels may be able to make. Figure O.5 shows the range of primary energy sources, energy carriers, and powertrains that either are used today in road vehicles or that are being investigated for possible future use.

Figure 0.5 **Possible Transport Fuel Pathways**



Source: Sustainable Mobility Project

It is important to underscore the word "potential." Technologies are enablers - nothing more than "building blocks." To actually contribute to sustainable mobility, technologies need to be incorporated into actual transport systems and these systems then need to be used widely. Moreover, such systems must still play their indispensable role in facilitating economic growth and development. They must be affordable, accessible, safe, secure and reliable. A society lacking transport systems with these characteristics would not be sustainable.

It is also important to underscore the fact that transport and energy systems typically are developed, manufactured and (in many instances) operated by private industry. This means that the development, manufacture, and operation of these systems must be capable of generating a profit. Even where governments assume an active role in producing and distributing energy or in operating transport networks, these operations cannot ignore commercial realities. Governments may sometimes take a longer-term view than companies. But there are limits. A society that bankrupts itself trying to force the premature adoption, or inappropriate use, of novel but uneconomic technologies is not sustainable. Neither is a society that in order to conserve financial resources hamstrings industry with regulations to make it operate in an economically unsustainable manner.

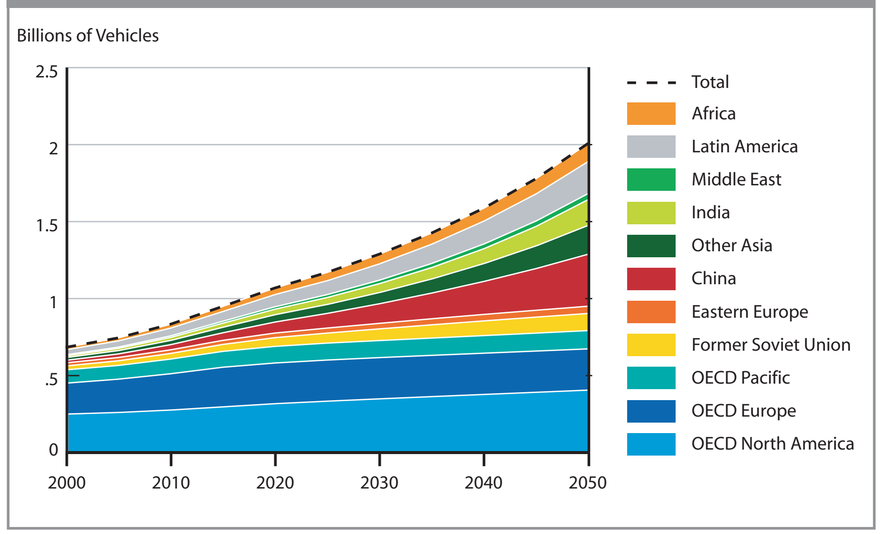
A. Light-duty road vehicles and the fuels that power them

Light-duty road vehicles – automobiles, light trucks, and derivatives such as sport utility vehicles and minivans – are by far the world's most numerous motorized transport vehicles. In 2000 there were nearly 700 million LDVs operating around the world. The SMP reference case projection indicates this number will grow to about 1.3 billion by 2030 and to just over 2 billion by 2050. Nearly all of this increase will be in countries in the developing world.

Light-duty vehicles are the principal providers of personal mobility today throughout most of the developed world. And this role is expanding rapidly throughout much of the developing world. Light-duty vehicles consume a large fraction of the fuel used by the transport sector and, in the course of consuming it, emit a large fraction of that sector's total emissions of "conventional" pollutants and greenhouse gases. Crashes involving light-duty vehicles are responsible for by far the largest share of transport-related deaths and serious injuries.

In short, light-duty vehicles are responsible both for a major share of

Figure 0.6 **Projected total stock of light duty vehicles by region**



Source: Sustainable Mobility Project calculations.

mobility's benefits and a major share of the challenges to achieving sustainable mobility. For this reason, a significant share of our report is devoted to assessing the potential of various technologies and fuels to help address these concerns while not sacrificing these benefits.

1. POWERTRAIN TECHNOLOGIES AND FUELS

At present, virtually all light-duty vehicles are powered by internal combustion engines (ICEs) and use petroleum-based fuels (gasoline or diesel). Our reference case projects that if present trends continue this will still be true several decades from now.

The large number of influencing factors, including different technical features, cost targets and exhaust standards, make a precise quantitative forecast of how diesel and gasoline engines' fuel consumption figures may develop impossible. Both gasoline and diesel engines will continue to improve, but it can be anticipated that until 2010 the fuel consumption of gasoline engines will decline more than that of diesel engines. Later, when diesel engines employing homogeneous charge (HCCI) technology are successfully developed, this trend will reverse.

Vehicle fuel consumption, and with it GHG emissions, are determined not only by engine efficiency but also by vehicle parameters. Forecasts give a potential for specific fuel consumption reduction for vehicles with direct drive (i.e., non-hybrid) until 2030 of around 20%, compared to current diesel vehicles as today's best practice. This assumes that all technical means of engine, transmission and vehicle technologies (such as aerodynamics, lightweighting, tires and efficient accessories) are taken together.

a) Hybrid-electric propulsion systems

The efficiency of the ICE can be enhanced and conventional and GHG emissions reduced through the use of hybrid-electric propulsion systems. The term "hybrid-electric propulsion system" covers a wide range of possible powertrain arrangements. All combine an ICE engine or fuel cell with a generator, battery, and one or more electric motors. But these components can be arranged in a variety of ways. And the electric motor(s) can bear a larger or smaller share of the load in propelling the vehicle. Generally speaking, a vehicle is only classified as a "full hybrid" if it can be propelled at least some of the time solely by the electric motor(s).

Although ICE and ICE hybrids will never be "zero emission" vehicles, their potential for CO_2 reduction per mile/km driven is substantial, especially if based on a future downsized clean gasoline- or diesel-powered ICE. Combined with advanced aerodynamics, lightweighting, the reduction of rolling resistance (including low rolling resistance tires) and high efficiency engines such as lean burning engines and high expansion cycle engines with their optimal operation, such systems may eventually produce even higher values in vehicle efficiency.

ICE hybrids can use "conventional" liquid fuels, blends containing biofuels and even 100% biofuels. If using the latter, hybrids (as well as conventional ICEs) could, under certain circumstances, qualify as "carbon neutral" transport systems.

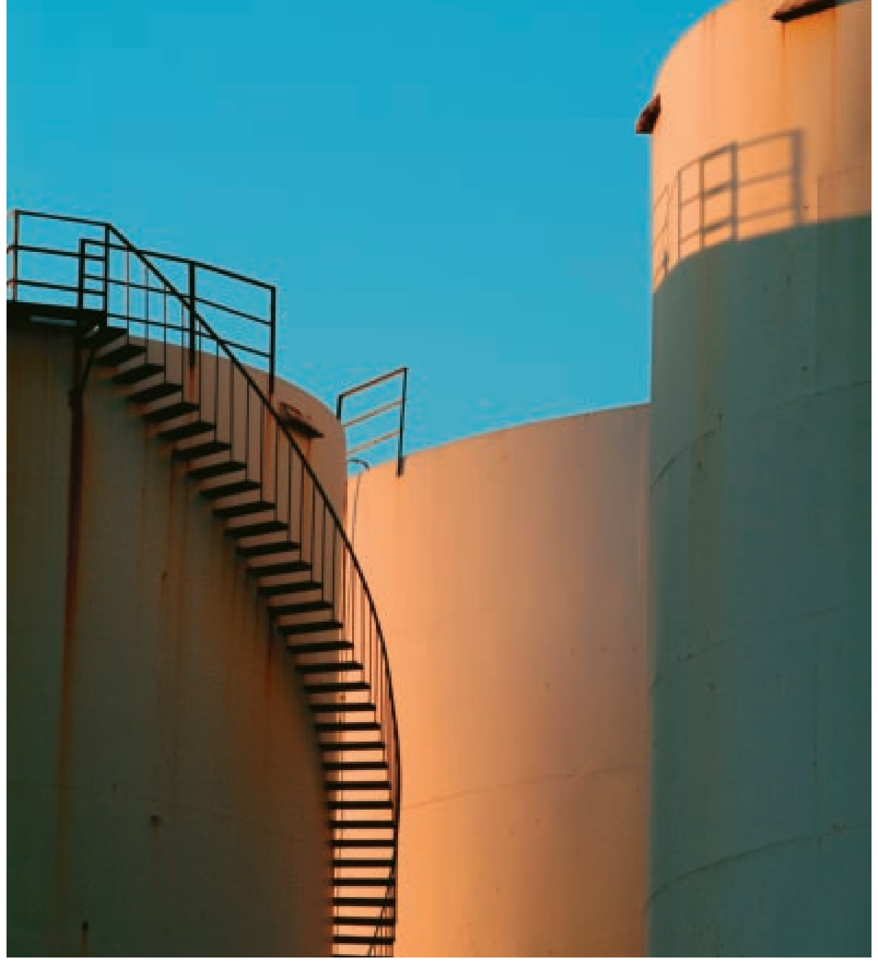
b) Fuel cells

Fuel cells convert fuel into electrical energy through an electrochemical rather than a combustion process. Fuel cell vehicles (FCV) offer both the highest overall propulsion system energy efficiency and, if run on hydrogen derived from carbon-neutral sources, the lowest GHG and conventional emissions. As with ICEs, their performance could be further enhanced by designs where batteries provide supplementary electrical power.

At present the most promising technology being applied is the proton exchange membrane fuel cell operating on hydrogen and utilizing on-board hydrogen storage. However, hydrogen storage technologies such as compressed hydrogen tanks, cryogenic tanks and metal hydride tanks are not yet suitable for mass production vehicles.

Other technical challenges to the wide-spread introduction of fuel cells include reducing today's high costs for fuel cell systems (including the amount of high cost precious metals required for the fuel cell stacks), improving cell membrane technology, and packaging the fuel cell system into a vehicle in a safe, reliable, attractive way that is affordable to consumers and operators.

Over the next decade and beyond, vehicle manufacturers around the world will be working to resolve these technical hurdles to bring down the cost of fuel cell systems to levels where they become commercially competitive.



c) Fuels that can be distributed through existing fuel infrastructures

For spark ignition engines (including hybrids), ***unleaded gasoline*** will continue to be the primary fuel. By 2010 unleaded gasoline will be available almost everywhere in the world, enabling the use of catalytic exhaust after treatment systems. Low sulphur gasoline and diesel fuel will be the norm in the developed world after 2010, and by 2030 probably in most developing countries. ***Ultra low sulphur fuels*** are not only necessary for vehicles with extremely low emissions but also for concepts that combine very low emissions with sharply reduced fuel consumption - for example, lean burn gasoline engines with NOx storage catalysts and ultra clean diesel engines equipped with a NOx storage catalyst or a particulate trap or both.

In the short to medium term, it is likely that gasoline and diesel, in addition to being more severely refined by hydrogenation processes in upgraded refineries, will increasingly contain – and may in certain circumstances be totally replaced by – ***blend components*** that are derived from primary sources other than crude oil. One such candidate fuel blend component is high quality diesel from natural gas, a so-called "gas-to-liquid" product produced from natural gas by the Fischer-Tropsch processing (also know as "FT diesel"). FT gasoline or naphtha is another possibility.

Although FT diesel produced from natural gas will not become a mainstream fuel, the potential exists to extend its availability through the use of other feedstock such as coal and biomass. In the case of coal this would need to utilize CO_2 sequestration to make it acceptable in terms of GHG emissions and content.

There also is much interest in ***bio-fuels or bio-fuel components*** as a means of reducing dependence on fossil fuels and reducing transport system greenhouse gas emissions. Alcohol fuels, methanol and ethanol generated from natural gas (in the case of methanol) or from biomass or other renewable sources can be used in gasoline engines. For diesel engines, bio-diesel containing biomass-derived fatty acid methyl esters or FAME (such as rapeseed methyl ester, RME) is an option.

New methods of producing "advanced" biofuels are being sought that increase the yield of biofuels or decouple their production from that of food. Two examples are the conversion of lignocellulosic material to fuel components by enzymes and biomass gasification followed by a Fischer-Tropsch process. (This is known as "biomass-to-liquid," or BTL).

All such processes have the potential to use a range of biomass feedstocks, including agricultural or municipal waste. Successful commercialization of these technologies has the potential to lower the cost of biofuels to levels that are closer to being competitive with conventional gasoline and diesel. The rate at which progress can be made is highly uncertain at present. Neither BTL (predominantly diesel) nor lignocellulosic gasoline component (ethanol) manufacture has yet been proven on a commercial scale.

Another relevant factor is feedstock logistics, which require biomass feed-stock production on a very large scale to be fully optimised. A world scale BTL plant (one capable of producing 1.5 million tonnes per year) would require woody biomass collected over an area half the size of Belgium. Alternatively a world scale lignocellulosic fermentation plant (0.2 million tonnes per year) would consume surplus straw from a planted area of wheat approximately one-tenth the size of Belgium.

d) Fuels requiring a separate fuel infrastructure

Alternative fuels that cannot be used as blend components, such as ***compressed natural gas (CNG), liquefied petroleum gas (LPG), di-methyl ether (DME) and hydrogen***, require a significant level of investment in delivery infrastructure. This infrastructure investment presents an economic barrier to their widespread use.

CNG compares well with diesel in particulate emissions in older vehicles. But the use of advanced exhaust treatment has largely removed any advantage CNG has over modern diesel-powered vehicles. It is not as widely available as a transport fuel as gasoline or diesel, and infrastructure development to improve accessibility has been slow. Nonetheless, it is favored over oil by many governments as resources are more evenly spread throughout the world and its use may reduce reliance on oil imports.

LPG shows improvements over gasoline for some, if not all, "conventional" pollutants. It is derived from both crude oil and natural gas condensate. Its refueling infrastructure is better established than that for natural gas, and it has gained some acceptance as an alternative to diesel and gasoline particularly in fleet vehicles. As a liquid fuel, consumer perception of safety is reasonable, and it is relatively affordable in comparison to some other alternative fuels. By 2030, it is likely that LPG refueling infrastructure will have expanded given that new refueling points are inexpensive to install. It is expected to remain as a niche fuel in most markets although it may be more widely used in selected national markets.

Hydrogen offers vehicle tailpipe emissions with zero CO_2. But completely CO_2-free mobility - that is, zero CO_2 from *both* the vehicle *and* the manufacture of the fuel - can only be achieved if hydrogen is produced from renewable sources or in conjunction with carbon-sequestration.

Technologies for manufacturing hydrogen from coal, natural gas or water electrolysis are already well known, and are applied commercially – not least in the oil industry where hydrogen increasingly is required for the production of low sulphur gasoline and diesel fuel. Almost 90% of the high-purity hydrogen produced today is derived from steam methane reforming of natural gas and this is expected to remain the dominant and most economic route for the foreseeable future. This process is not carbon neutral; carbon emissions from the production of hydrogen using water electrolysis depend on the fuel used to generate the electricity. Technology advances in hydrogen production and distribution will be required to drive down the cost and increase the energy efficiency of all these processes.

e) Potential impacts on mobility sustainability of vehicle propulsion system/fuel combinations

The propulsion systems and fuels described above are in different stages of development. Some are already in commercial use. Others are in early stages of development. Given these differences, any estimates of the performance or the cost characteristics of various possible propulsion system/ fuel combinations when in full-scale commercial production at different times in the future must be speculative. Instead, the estimates provided in this report should be read as illustrative of the magnitude of the challenges to be overcome to make these technologies commercially viable.

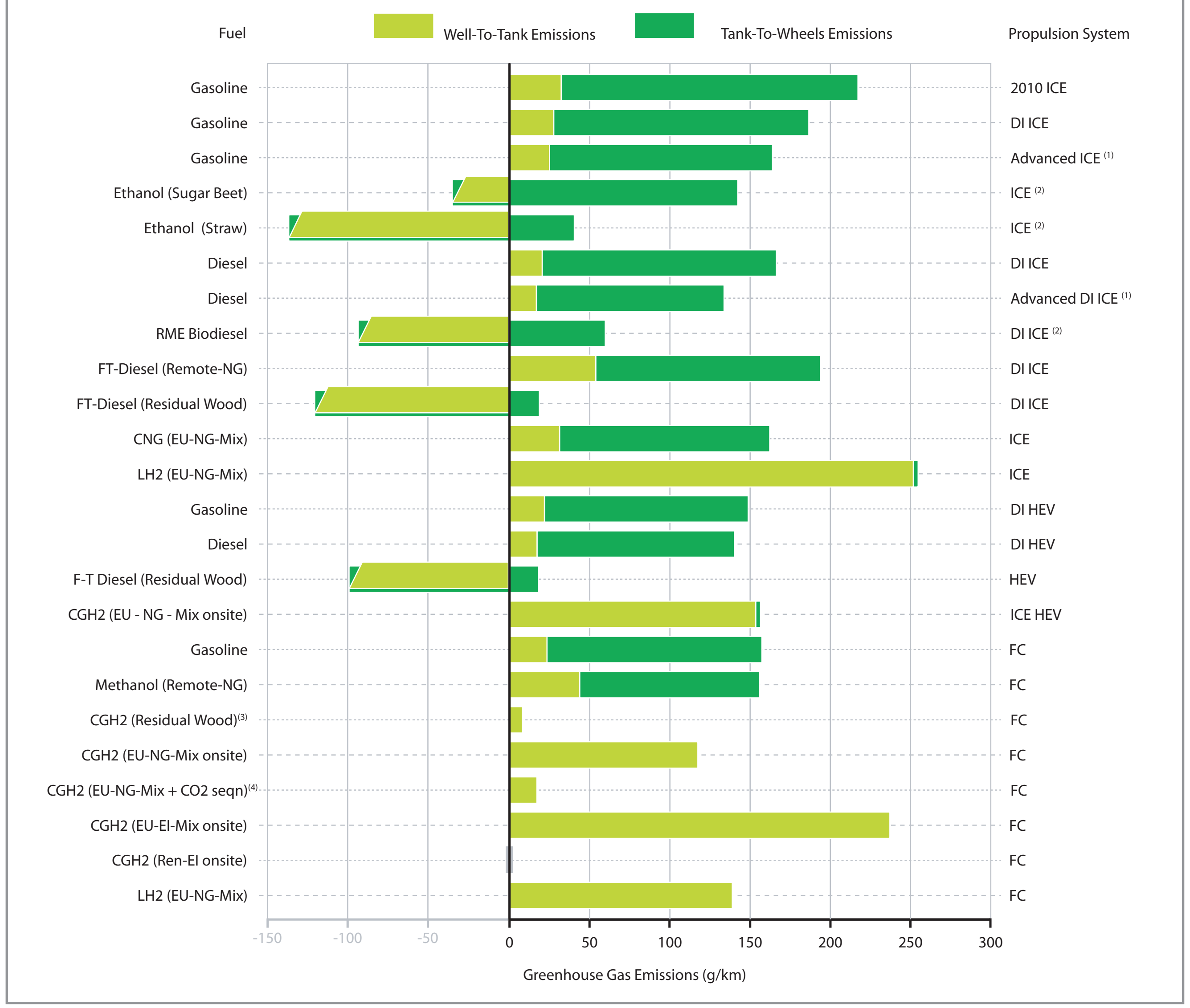
• GHG emissions characteristics

Simply considering the GHG emissions produced by the fuel consumed by a vehicle can give a misleading impression of the true GHG impact of the propulsion system/fuel combination since reductions due to vehicle improvements may be counterbalanced – or sometimes even exceeded – by increases resulting from the production and distribution of the fuel. Therefore, to estimate the potential impact of propulsion system/fuel combinations on greenhouse gas emissions, it is necessary to use a methodology known as "Well-to-Wheels (WTW) analysis." This approach considers not only the GHGs produced when the fuel is used in the vehicle ("Tank-to-Wheels" - TTW), but also the GHGs emitted in the fuel's production and distribution ("Well-to-Tank" – WTT), whether from crude oil, biomass or other primary energy sources.

Figure O.7 shows WTW emissions for various fuel/powertrain combinations as estimated by the project. Each combination is separated into its WTT and TTW components. All combinations using ICE engines and any fuel other than hydrogen have relatively high TTW emissions. Advanced ICE propulsion systems (including hybrids) achieve lower TTW emissions by reducing the amount of fuel required to propel a vehicle a given distance. They also show reduced WTT emissions due to the reduced need to produce the fuel they use. TTW emissions only disappear (or nearly so) when hydrogen is used as a fuel.

The WTW GHG emissions of vehicles powered by hydrogen depend almost entirely on the process used to produce and distribute the hydrogen. This varies widely. Indeed, some hydrogen production methods have such high WTT emissions that the WTW emissions exceed those of current gasoline ICE systems.

Figure 0.7 **Well-To-Wheels (Well-To-Tank + Tank-To-Wheels) greenhouse gas emissions for various fuel and propulsion system combinations**



Notes: [1] Estimated by VKA [2] Estimated by BP, from GM data [3] Net output from energy use in conversion process [4] Based on Hydro figures
Source: Sustainable Mobility Project calculations.

Biofuel/ICE combinations sometimes have very low WTW emissions. This is due to the CO_2 emissions produced by fuel production and distribution (the WTT emissions) being negative, reflecting the fact that the plants from which the biofuels are produced are net absorbers of carbon. All WTT studies of which the SMP is aware stress the difficulty of accounting properly for the GHG emissions generated in connection with biofuels production (some of which are much more potent GHGs than CO_2). They also stress the difficulty of determining the appropriate carbon sequestration credits to allocate to the growing of the biomass that later is converted into biofuels.

• Vehicle ownership and operating costs and the cost-effectiveness of various powertrain/fuel combinations in reducing GHG emissions

Cost is a major factor in determining which technologies and fuels will be used in the future. While the cost of future technologies and fuels are inherently uncertain, we know enough about some of them to enable the generation of "order of magnitude" estimates. As a source of such estimates, the SMP drew on a study conducted jointly by the European Council for Automotive R&D (EUCAR), Conservation of Clean Air and Water in Europe (CONCAWE), and the Joint Research Center of the EU Commission (JRC) released in November 2003. *(EUWTW 2004)*

Among other things, this study (referred to in this report as the "European WTW Analysis") estimated vehicle ownership and fuel costs for a range of power-

Table 0.1 **European WTW analysis "5% Passenger car Transport Distance Substitution" Scenario for various alternative fuels and powertrains**

Fuel	Powertrain	GHG Savings			Additional Cost	
		Mt CO_2 equiv	Change from Reference Case	Cost per tonne CO_2 Equiv Avoided per annum (Euros)	Per vehicle using alternative fuel and/or powertrain (Euros per annum)	Per 100 km per vehicle using alt fuel or pt (Euros per annum)
Conventional	Hybrids	6	-16%	364	141.8	0.89
CNG	PISI	5	-14%	460	156.0	0.98
	Hybrid	12	-32%	256	219.9	1.38
Syn diesel fuels						
FT-diesel ex NG	CIDI+DPF	-5	14%	n.m.*	49.6	0.31
DME ex NG	CIDI	1	-3%	2,039	156.0	0.98
Ethanol	PISI					
Sugar beet						
Pulp to fodder		14	-38%	418	425.5	2.67
Pulp to EtOH		12	-32%	563	461.0	2.89
Pulp to heat		24	-65%	254	432.6	2.71
Ex wheat		5	-14%	1,812	581.6	3.64
FAME	CIDI+DPF					
RME						
Glycerine as chemical		16	-43%	278	326.2	2.04
Glycerine as heat		14	-38%	345	354.6	2.22
SME						
Glycerine as chemical		22	-59%	217	340.4	2.13
Glycerine as heat		20	-54%	260	368.8	2.31

*n.m. = not meaningful

Source: **EUWTW 2004**, additional calculations by the Sustainable Mobility Project.

train/fuel combinations and the cost per tonne of GHG emissions avoided for each such combination. It did this by assuming that vehicles using powertrain/fuel combination replaced 5% of projected EU-25 travel in 2010 -- 225 million vehicle kilometers. At an assumed average annual vehicle utilization rate of 12,000 km, this required a parc of 14 million vehicles.

The study also assumed that in those instances where a fuel is not capable of being distributed through existing distribution channels, 20% of the EU-25's 100,000 refueling stations – about 20,000 refueling stations – would need to be equipped to dispense the fuel.

As the authors of the analysis are careful to point out, this scenario was an analytical exercise – not a judgment that such a level of market penetration would be either technologically possible or economically practical in Europe by 2010.

Although the European Well-to-Wheels analysis examined nearly the full range of the powertrain/fuel combinations shown in Figure O.7 above, we decided to make use of only those combinations that seem potential candidates for adoption in the near term. The authors of the European WTW analysis considered their estimates of the additional costs of vehicles powered by fuel cells to be highly problematic. A high degree of uncertainty also exists concerning the cost of producing and distributing hydrogen to power vehicle fuel cells. The same can be said for the cost of producing "advanced" biofuels. Estimates vary widely concerning these costs especially for hydrogen and advanced biofuels produced using processes that do not themselves result in the emission of significant volumes of CO_2.

For those powertrain/fuel combinations shown in Table O.1, the additional annual cost for each vehicle using an alternative fuel and/or powertrain ranges from about €50 to nearly €600. This translates into an additional cost per 100 km operated by each vehicle of between €0.31 and €3.64. In terms of cost per tonne of CO_2 equivalent avoided per year, the range is from about €200 to about €2000.

This analytical exercise was based on "virtual" European vehicles, and the fuel manufacturing and distribution costs shown are estimated based on European conditions. In other parts of the world vehicle and fuel costs and the cost-effectiveness of different vehicle/fuel combinations in reducing GHG emissions are likely to be quite different.

Nor is it possible to use these figures to judge the potential cost of substantially "scaling up" the penetration rates of various powertrain/fuel combinations. Economies of scale and the impact of cumulative experience would both need to be taken into account to conduct such an exercise for the EU-25. Moreover, the five percent of EU-25 LDV travel demand by 2010 used in the European WTW Analysis scenario represents only about 1.4% of total world LDV vehicle kilometers projected for that year. In addition, LDVs world-wide are projected to account only for some 43% of total worldwide WTW transport-related GHGs in 2010.

Nevertheless, the results of the European WTW Analysis represent extremely useful order-of-magnitude estimates of added cost and cost-effectiveness in terms of reducing GHGs for the range of vehicle/fuel combinations now being considered for widespread adoption in the decades ahead.

2. VEHICLE TECHNOLOGIES OTHER THAN PROPULSION SYSTEMS

The potential for improving the sustainability of light-duty vehicles through the use of advanced vehicle technologies is not limited to propulsion systems and fuels. Changes in the materials used in vehicle construction, safety technologies employed, enhanced electronic systems made available, the characteristics of the vehicle's tires, and other design features can also impact one or more of our indicators of sustainable mobility.

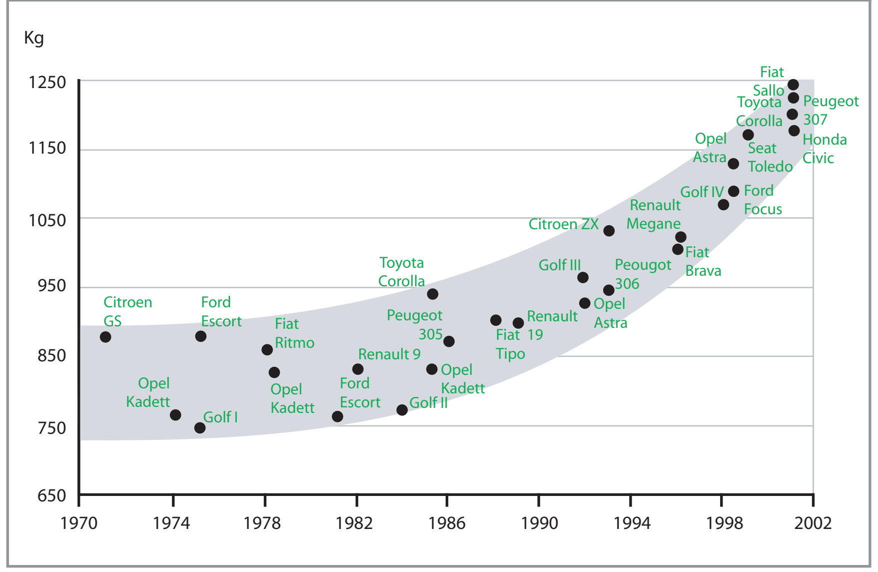
a) Technologies to reduce vehicle weight

On average, light duty vehicle weight in Europe has increased by approximately 30% over the last 30 years. Over this same period, average light duty vehicle weight in the United States, which initially was significantly higher than in Europe, declined from 1845 kg in 1975 to 1455 kg in 1981/82. Thereafter, it began to rise again. By 2003 it had returned nearly to its 1975 level, growing 24% since 1981/82.

Increases in average vehicle weight in both the US and Europe reflect the combined effect of two trends – growth in the average weight of vehicles within individual vehicle classes, and increases in the proportion of total vehicle sales represented by larger vehicle classes. In our report we deal almost exclusively with the first of these trends.

What explains the within-class weight increase? As vehicles have evolved, they have added more and more features – to increase safety, enhance driving characteristics, lessen noise, reduce emissions and improve comfort, among other things. This trend has involved adding new components to the vehicle interior, body, and chassis. Increasingly, these components have been electrical or electronic and this has required more wiring. The capacity of electrical systems has had to be increased to handle the additional electric power demands. Heavier cars also require extra equipment to maintain desired driving performance. There have been reductions in the weight of individual components through improved design and materials substitution. But these reductions have been more than offset by the growth in weight due to the growth in vehicle functionality.

Figure 0.8 **Weight of European compact cars at date of model introduction**



Source: **FKA 2002**

There are two main ways in which within-class vehicle weight can be reduced. First, by design changes related to the overall vehicle appearance as well as changes due to the geometry available for each part. Second, by direct substitution of lighter materials for heavier materials - for example by using more aluminum, high-strength steel, magnesium and plastics. Often these are done at the same time and are interdependent. In turn, weight reduction creates the potential for further weight reduction. Lowering the weight of a vehicle also allows the use of a smaller, lighter engine while maintaining performance.

In most cases, a lightweight solution will be more expensive than ordinary mild steel designs. Consequently, these solutions will not be competitive unless the customer is prepared to accept some premium for reduced weight or unless the solutions in some way simplify production and/or increase safety. Different materials will provide different potential for weight reduction, and also different impact on the component cost.

A rule of thumb is that a 10 % reduction in vehicle weight can produce a 5-7% fuel saving (in mpg terms) provided the vehicle's powertrain is also downsized. (IPAI 2000) If the vehicle's weight is reduced but no change is made in the powertrain, the fuel savings will be less – generally about 3-4%. Actual savings depend on the vehicle in question and the driving cycle. Adopting the mid-point of this 5-7% range, and translating percentages into absolute numbers yields projected savings of 0.46 liter of gasoline saved per 100 km driven for each 100 kilograms of mass reduced. (This value applies to a midsized North American vehicle with a curb weight of 1532 kilograms.) Over the life of a vehicle (assumed to be 193,000 km), this produces savings in CO_2 emissions of 25.3 kilograms for each kilogram of reduced weight.

b) Intelligent Transport Systems technologies

Intelligent Transport Systems (ITS) technologies have the potential to enable individual travelers, vehicle operators and governmental authorities to make transport decisions that are better informed, more intelligent, and safer.

ITS technologies include a broad range of wireless and wired communications-based information, control and electronics technologies, most of which were originally created for the telecommunications, information technology, and defense sectors prior to being applied to traffic and transport. Among critical ITS enabling technologies are microelectronics, satellite navigation, mobile communication and sensors. When integrated into vehicles and into the transportation system infrastructure, these technologies can help to monitor and manage traffic flow, reduce congestion, provide alternate routes to travelers and save lives.

c) Technologies for reducing aerodynamic drag

Aerodynamic drag is the result of pressure and friction forces that are transmitted to a vehicle as it moves through the air. The vehicle's size and exterior shape and the function it is designed to perform are all major influencing factors. Functional requirements (the number of occupants a vehicle is designed to carry, luggage space, pickup box, trailer towing, off-road capability and performance) are important parameters in determining overall aerodynamic resistance.

Many of the most obvious opportunities for drag reduction in LDVs have been incorporated into vehicles, especially passenger cars. Today, aerodynamic drag for LDVs is at historically low levels. Further improvements are likely to be achieved incrementally in the short term rather than by major design breakthroughs.

Advanced technology does offer some potential. Wood, who estimates that 16% of total energy consumed in the US is used to overcome transport vehicle drag, provides a useful overview of the role of advanced aerodynamic technology on potential vehicle fuel consumption. *(Wood 2004)* But, realistically, given customer preference for the many utilitarian and functional aspects of today's LDVs and the economic pressures in the marketplace, designers' will probably only achieve minor additional reductions in aerodynamic drag in the next several years. However, there may be more opportunities for reducing aerodynamic drag for trucks and buses.

d) Technologies for reducing rolling resistance

Rolling resistance is defined as energy dissipated by a tire per unit of distance covered. It can only be overcome by the application of more energy. Rolling resistance thus affects fuel consumption. "Green" tires currently on sale can reduce fuel consumption by 3-8%. New generation "green" tires may yield additional reductions of 2-9% in fuel consumption.

To minimize fuel consumption, tires must be inflated properly. Field studies on French roads have revealed that more than 50% of cars are driven with tires inflated 0.3 bars below than the prescribed pressure or even lower. This results in a significant increase in rolling resistance - plus 6 % when 0.3 bars below the recommended pressure, and plus 30 % when 1.0 bars below. A 30% increase in rolling resistance increases fuel consumption by 3-5%. Under-inflated tires are also prone to irreversible damage. This explains the interest in technologies that enable drivers to be informed that their vehicle's tires are not inflated properly while driving.

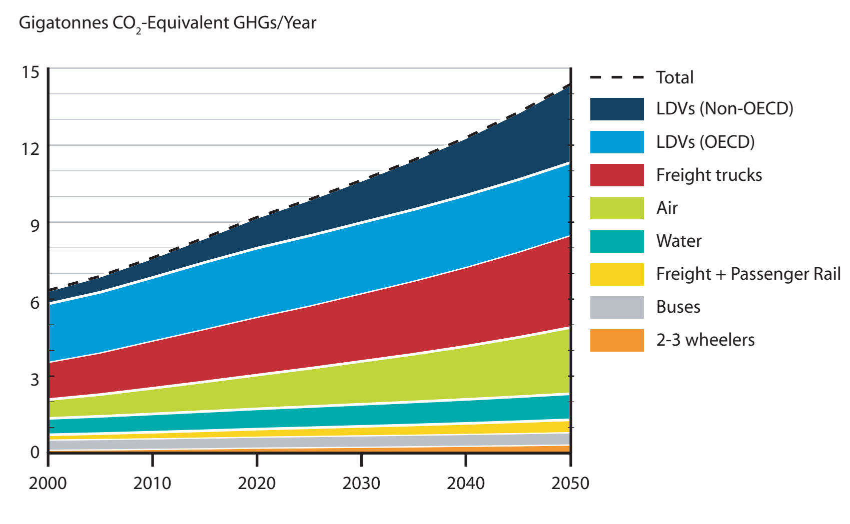
The primary purpose of a vehicle's tires is to enable safe operation in all types of weather and under all road conditions. So any reduction in rolling resistance has to be achieved without compromising tire safety performance. Tire characteristics also have a significant impact on a vehicle's ride, handling performance and sales appeal.

B. Applicability of these vehicle technology and transport fuels "building blocks" to road vehicles other than LDVs

While light-duty vehicles are the world's most numerous motorized transport vehicles, other road vehicles both contribute significantly to personal and goods mobility and are an important element in the challenge of making mobility sustainable. Figure O.9 shows projected reference case WTW CO_2 emissions by mode for the period 2000-2050.

Efforts are underway to bring emissions from these vehicles under greater control. One of the most important steps is to shift from two-cycle to four-cycle engines. Two-cycle engines are more polluting than four-cycle engines, since oil must be added to the fuel. Some countries have enacted such stringent controls over emissions that the sale of new 2 and 3-wheelers powered by two-cycle engines has been effectively banned. This will produce a significant improvement in emissions performance. But additional initiatives will be needed where 2 and 3-wheelers exist in large numbers if they are to cease being a major source of conventional emissions. Examples of such steps are provided in the body of our report.

Figure 0.9 Reference case projections of transport-related WTW CO_2 emissions by mode, 2000 - 2050



Source: Sustainable Mobility Project calculations.

Powered 2 & 3-wheelers.
One vehicle type that plays a very important role in providing personal (and also sometimes freight) mobility in several parts of the developing world is the powered 2 and 3-wheeler. Indeed, in some countries of South and East Asia, powered 2 and 3-wheelers constitute the majority of motorized road vehicles at present. They are inexpensive and provide mobility for millions of families. They can facilitate a household's transition from non-motorized means of transport (such as bicycles) to conventional light-duty vehicles. On a per vehicle basis they use less fuel than an automobile or light truck. But they contribute disproportionately to "conventional" pollution.

"Heavy" road vehicles.
Trucks of various sizes and shapes are the principal transporters of freight over land. Buses are the workhorses of many local and regional public transport systems. Buses also play an important role in intercity personal transportation, especially in the developing world. Both trucks and buses are powered by internal combustion engines and utilize many components that are similar in design and construction (though not necessarily in size) to those found in light duty vehicles.

"Heavy" road vehicles account for a significant share of transport-related energy use, greenhouse gas emissions, and "conventional" emissions (especially NOx and particulates). Increasing attention is being devoted to improving the energy efficiency of the powertrains used in these vehicles - at present overwhelmingly diesels - and also to reducing their "conventional" emissions. Engines powered by natural gas, methanol, and ethanol already are already being used in selected truck and bus applications around the world.

Efforts are now underway to apply new propulsion system technologies such as hybrids and fuel cells to selected truck and bus types. These initiatives are less well known to the public (and even to those particularly interested in sustainable mobility) than those associated with light-duty vehicles. However, the fuel and emissions savings gained by applying a hybrid system to a city bus (for example) can reduce CO_2 emissions by as much as by applying the same technology to several light duty passenger vehicles.

C. Transport vehicles other than road vehicles

SMP member companies lack significant expertise in these transport modes, but the report provides some indication of what the project understands to be the potential of various technologies to enhance sustainability performance for each transport sector. Certain of the powertrain technologies and fuels discussed above might find application in railroad engines, oceangoing ships, and vessels operating on inland waterways.

Commercial aircraft present a particular challenge. The efficiency of aircraft engines is increasing and weight reduction through improved aerodynamics and the use of lightweight materials are expected to continue to be important sources of greater energy efficiency in commercial aircraft. Even so, the rate of demand growth projected for this form of mobility is so great that even with these improvements both energy use and GHG emissions are projected to increase faster than in any other transport sector. Additional efficiency improvements may still be possible. For example, some consideration has been given to using hydrogen as a commercial aircraft fuel. This is unlikely to occur before the latter half of the 21st century – if even then.

IV. Approaches to advancing the achievement of the seven goals

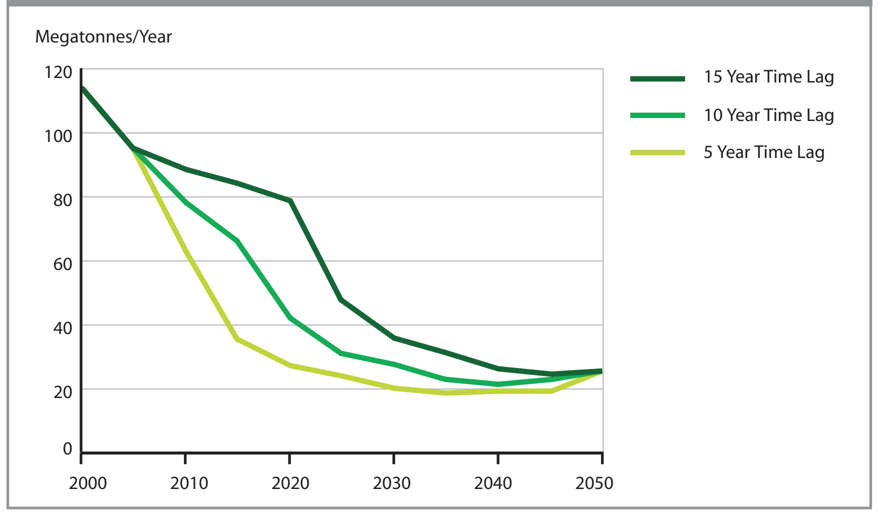
At the beginning of this Overview, we identified seven goals that, to the extent that they can be achieved, will enable mobility to be made more sustainable. The goals themselves are directed to society as a whole; we are proposing them as the first step in what could become a continuing dialogue among a broad range of stakeholders.

• Reduce transport-related conventional pollutants to levels where they do not constitute a significant public health concern anywhere in the world.

We believe that in the developed world this goal will be achieved by 2030. Indeed, it might be achieved as early as 2020. Reference projections used in the project indicate the progress that is possible given current trends in technology and vehicle use. To ensure that these projected reductions do in fact occur, it will be necessary to focus much more on identifying "high emitter" vehicles and repairing them or removing them from operation.

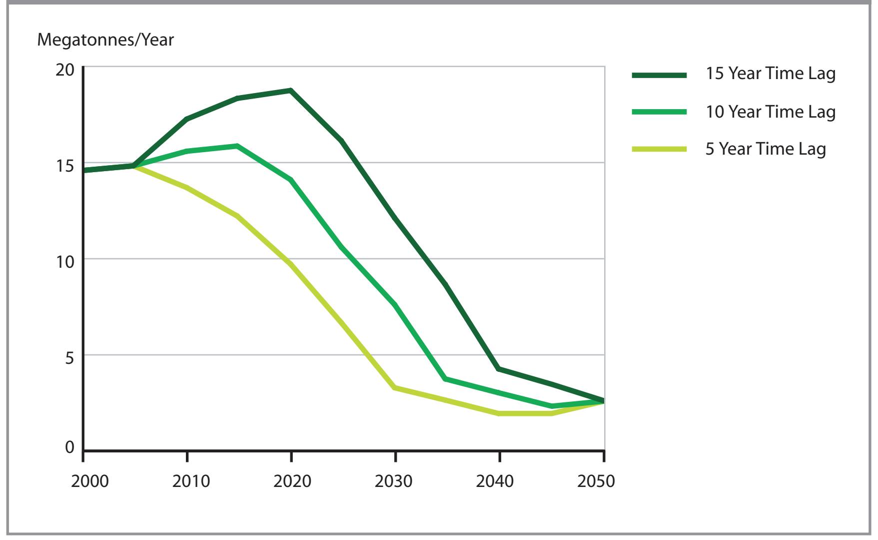
"High emitter" vehicles are vehicles that discharge far greater levels of emissions than are permitted by the regulations under which they were certified. They have been shown to be responsible for a greatly disproportionate share of total emissions. As more and more vehicle fleets reflect current extremely tough emissions standards, "high emitter"

Figure 0.10a **Non-OECD regions: Carbon Monoxide (CO) emissions by year depending on the time lag in implementing developed world emissions standards**



Source: Sustainable Mobility Project calculations.

Figure 0.10b **Non-OECD regions: Nitrogen Oxide (NOx) emissions by year depending on the time lag in implementing developed world emissions standards**



Source: Sustainable Mobility Project calculations.

vehicles will be responsible for a larger and larger share of the remaining emissions. Various technologies permitting these vehicles to be readily identified are coming into use.

These new technologies may require vehicle users to accept a higher level of government intrusion than many have been accustomed to in the past. Increasingly, reducing transport-related emissions of conventional pollutants in the developed world will be a political and social problem rather than a technological or economic one.

In the developing world, it should be possible to reduce transport-related conventional emissions well below the levels projected in our reference case. It is not realistic to expect the stated goal to be achieved throughout the developing world as soon as it is achieved in the developed world.

Important determinants of how rapidly emissions can be reduced in the developing world will be the affordability of the necessary technologies and fuels, and the impact that aggressive efforts to reduce conventional transport-related emissions might have on the ability of the transport systems in these countries and regions to support projected rapid rates of economic growth.

To complete the emissions reduction task in the developing world eventually will require extending the use of the emissions reduction technologies and fuels that are now being adopted by developed countries across the entire world. As this occurs, developing countries will have to pay growing attention to the problem of "high emitters" discussed above.

Dealing effectively with "high emitters" may prove to be a greater challenge for developing countries than developed. But the challenge cannot be avoided if progress is to be made towards sustainable mobility. As a recent report on this subject observed: "It is better to have realistic standards that are vigorously enforced than very stringent standards that cannot be effectively enforced."

• Limit transport-related GHG emissions to sustainable levels

We accept that society's long-term goal should be nothing less than to eliminate transportation as a major source of greenhouse gas emissions. Yet even under the most favorable circumstances, achieving this goal will take longer than the time frame of this report.

Important progress can be made during the next two or three decades. Prior to 2030, where economically practical and politically acceptable, SMP members believe that the following actions aimed at "bending the transport-related GHG emissions curve downward" should be undertaken:

- The energy efficiency of transport vehicles should be improved consistent with customer acceptance and cost-effectiveness.
- The technological foundation should be laid for the eventual elimination of the effects of fossil carbon in transport fuel. This likely will require both the development of hydrogen as a major transport energy carrier and the development of advanced biofuels.
- Where new fuel infrastructures are required to permit the eventual elimination of the effects of fossil carbon in transport fuel, planning should be undertaken and, if practical, construction should begin.

To reach the goal stated above, society will have to stretch in the decades beyond 2030. What eventually may be required is a complete change in the technologies used to power transport vehicles and in the fuels that these vehicle use. Also, it may be necessary to change the ways in which people use transportation.

This is because every strategy for lessening transport-related GHG emissions can be reduced to four basic elements: (1) reduction of the amount of energy that a vehicle uses to perform a particular transportation activity; (2) reduction of the GHG emissions generated by the extraction, production, distribution, and consumption of the vehicle's fuel; (3) reduction of the total volume of transport activity performed; and (4) alterations to the modal mix of transport activity.

These four elements are not necessarily independent. Actions designed to impact one may reinforce or detract from the effectiveness of another. But these are the only "levers" that exist. How these elements influence GHG emissions, and the time frame over which influences of various magnitudes can be expected to occur, are detailed in our report. Our conclusion is that no single approach offers a "magic bullet" that can produce GHG reductions quickly and inexpensively on the scale required. But some do show significant promise.

For example, "carbon neutral" transport systems of the types discussed in the report should be brought into general use around the world if their actual effectiveness in reducing GHGs turns out to be as significant as it presently appears, and if production and operating costs can be reduced to levels either that users find affordable or that governments can incentivize on a sustainable basis.

In addition, demand-channeling measures can complement technology-based measures usefully both by increasing the demand for more nearly "carbon neutral" transport systems and by altering the level and mix of transport activity in ways that reduce GHG emissions, although their short-run effectiveness is likely to be limited. Finally, although transport clearly has a significant role to play in reducing total GHG emissions, it needs to be kept in mind that considerations of cost-effectiveness, rather than arbitrary assignment of "responsibilities," should drive society's GHG emissions reduction efforts.

(Babiker, Baustita, Jacoby and Reilly 2000)

• Reduce the number of transport-related deaths and serious injuries worldwide

In most parts of the world, the rate of deaths and serious injuries per unit of transport activity is falling and is likely to fall further. Yet this decline is being swamped in many places by the rapid rate at which transport activity is growing.

As a result, total global transport-related deaths and serious injuries are increasing. In those countries experiencing the highest growth in transport activity, a disproportionate share of individuals being killed or seriously injured in accidents are pedestrians, bicyclists and the users of motorized 2 and 3-wheelers. *(See Figure O.11).*

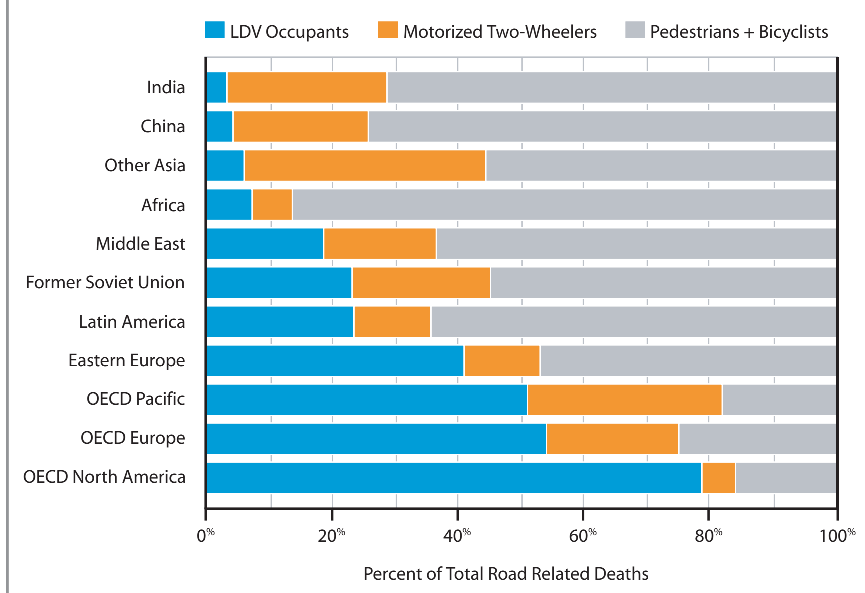
We regard this situation as unacceptable. All countries should pursue aggressive strategies to reduce the number of transport-related deaths and injuries, especially deaths and injuries related to road vehicles.

In the industrialised world and in some middle-income countries, these strategies should aim to achieve major reductions from current levels. In lower income countries, the goal should be to curb the growth in deaths and injuries and put society on a path leading to rates of deaths and injuries comparable to those in the developed world. These efforts should focus especially on vulnerable groups in the population – pedestrians, bicyclists, and operators of 2 and 3-wheeled motorized vehicles.

Programs to reduce deaths and serious injuries should address the full range of factors contributing to vehicle-related deaths and serious injuries, including driver behavior, improvements in infrastructure and the development and deployment of improved technologies for crash avoidance and injury mitigation.

Technologies to aid authorities in the enforcement of traffic regulations are becoming increasingly available and affordable. It is possible that much vehicle user conduct responsible for a large share of accidents today involving death or serious injury - for instance, driving while alcohol-impaired or speeding - could be eliminated or reduced drastically by the use of these technologies. The same issues of government intrusiveness mentioned earlier in reference to "high emitting" vehicles could arise concerning these safety-related technologies. Again, the issue increasingly will be political and social rather than technological or economic.

Figure 0.11 **Share of total road related deaths by category of road users**



Source: Sustainable Mobility Project calculations using data from **Koornstra 2003**

• Reduce transport-related noise

If GHG emissions represent the ultimate example of a sustainable mobility challenge that is global both in origins and in the strategies required for its eventual resolution, transport-related noise can probably be seen as the exact opposite – a challenge that is rooted in the local level and requires locally-tailored solutions if it is to be effectively and efficiently resolved.

At present different localities can place quite different priorities on the importance of dealing with transport-related noise and also on the types of remedies that are considered acceptable for dealing with it. But a common set of elements from which communities might develop a noise-reduction strategy does exist. It includes using road surfaces that significantly dampen noise; constructing noise barriers in noise-sensitive areas; enacting and enforcing regulations restricting the modification of vehicles in ways that create greater noise and/or allow such vehicles to be operated in a manner that produces unnecessary noise; and continuing to improve the noise performance of transport vehicles.

• Mitigate congestion

Transportation congestion cannot be eliminated completely without destroying transport's vital role in enabling economic growth. But its effects can be mitigated substantially. In most cases, congestion, like noise, is a local or at worst regional problem. In some situations congestion has such wide-spread impact that it threatens the performance of transport systems and economies on a national scale.

As with noise, a range of mitigating elements exists from which to choose in addressing congestion. Their appropriateness, either individually or in combination, depends on the details of each situation as well as on the political and social context within which congestion arises:

Infrastructure capacity can be expanded to accommodate demand-led growth. This appears to be most relevant in rapidly growing urban areas in the developing world. But in the SMP's view building additional transport capacity should never be the only (or even the principal) approach to mitigating congestion. Additional infrastructure capacity can also be created through various Intelligent Transport System (ITS) technologies.

Infrastructure planning can be focused increasingly on the elimination of "choke points" that prevent critical elements of transport infrastructure from being used efficiently.

Where practical and politically acceptable, transport demand growth can be absorbed by making better use of existing mobility systems and infrastructure. Pricing strategies of various types are being used in an increasing number of places, although their use remains controversial. In the future, constraints on the use of road pricing strategies are much more likely to be political and social rather than technological or economic.

• Narrow the mobility opportunity "divides" that exist between the world's poorest and richest countries and within most countries.

While it is clearly necessary to mitigate the negative consequences associated with increasing mobility, that is not sufficient by itself to make mobility sustainable. Sustainable mobility requires both that "essential human or ecological factors not be sacrificed today or in the future" and that "society's needs to move freely, gain access, communicate, trade, and establish relationships" be met. Only by doing both can mobility fulfill its indispensable role in improving the standard of living of all the world's people.

Many of the world's peoples are hampered in their efforts to better their lives by poor mobility opportunities. In some of the poorest countries and regions, mobility opportunities are a small fraction of what they are in the rest of the world. And in most countries, there are large differences in the mobility opportunities enjoyed by the average citizen and members of certain groups – the poorest, the handicapped and disabled, the elderly, etc. These mobility opportunity divides must be narrowed if mobility is to become sustainable.

(a) Narrowing the "mobility opportunity divide" between the poorest countries and countries of the developed world.

Today the average inhabitant of Africa travels about one-tenth the number of kilometers per year as the average inhabitant of OECD Europe or OECD Asia. The SMP's reference case suggests this ratio is unlikely to change significantly in the next 50 years. The lack of mobility opportunity reflected in this difference not only illustrates the lack of economic opportunity that exists today in much of Africa but is also a major cause of this lack of economic opportunity. While Africa is the extreme example of how lack of mobility opportunity inhibits economic opportunity, it is by no means the only one. To narrow the mobility opportunity divide that exists between many of the world's poorest countries and the countries of the developed world, the SMP believes it is necessary to:

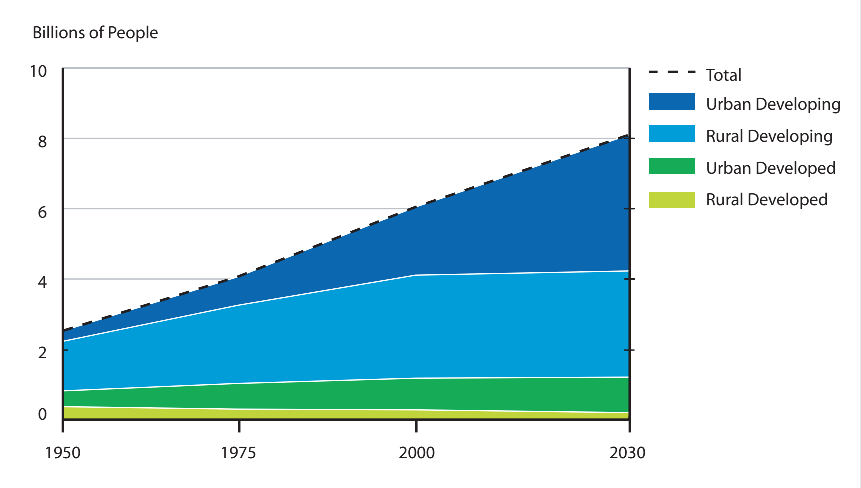
- Lower the cost of transport in rural developing areas by providing basic means of access where it now is lacking.
- Encourage the development of inexpensive motorized vehicles that are appropriate to the harsh road environments typically found in these countries.
- Ensure that inhabitants of the poorest countries achieve the mobility opportunities necessary to permit economic development even if by doing so this increases transport-related GHG emissions.

Mobility 2001 pointed out how rapidly the world is urbanizing. In 1950, only about 30% of the world's population lived in urbanized areas. Fifty years later this had reached almost 50%. Urbanization is expected to continue unchecked. The UN projects that by 2030 the share of the world's population living in urbanized areas will reach 60%. *(See Figure O.12). (UN 2001)*

However, while urbanization is intensifying, the number of people living in rural areas of developing countries also continues to grow. The 3.02 billion persons that the UN projects will be residing in the developing rural areas in 2030 will exceed the total of the world's population in 1950.

The inhabitants of many of these rural areas lack access to essential goods and services because they lack basic mobility infrastructure. About 900 million people living in rural areas, or about 30% of the total, even lack access to an all-weather road. Such people cannot readily reach doctors or other health care personnel, attend school, market their products, or visit friends and relatives. Institutions such as the World Bank have been trying to facilitate the construction of rural roads in these areas. The efforts should be encouraged with the proviso that such new roads avoid unacceptable harm to the environment.

Figure 0.12 **Urban and rural populations in the developed and developing worlds 1950-2030**



Source: Adapted from **UN 2001**

In addition to roads, inhabitants of isolated rural areas also need inexpensive motorized vehicles designed to operate in the extreme conditions often found in such parts of the world. Motorized 2 and 3-wheelers and simple tractor-derived vehicles are already helping to fill this need in parts of Asia. But these vehicles emit high levels of pollutants and have relatively poor energy efficiency, making them significant GHG contributors. They are also sometimes very unsafe. While such vehicles need not incorporate the latest technologies, they do need to be equipped with basic emissions control systems and be designed and constructed with safety in mind.

In the SMP's opinion, the growth in mobility opportunities in very poor countries is such an important enabler to economic development that any resulting increases in GHG emissions should not be considered by developed countries as a reason for discouraging this growth. Rather, developed states should help the poorest countries control growth in their transport-related GHG emissions in ways that do not make their newly achieved mobility opportunities unaffordable. To the extent that this proves to be insufficient, developed countries need to consider ways to accommodate the growth in GHG emissions from the poorest countries.

(b) Narrowing the mobility opportunity divides that exist within most countries

Significant mobility opportunity divides also exist within most countries, reflecting (and contributing to) income disparities and social differences. As urban areas grow in size but decline in density, it is becoming more and more

difficult merely to preserve existing mobility opportunities, let alone to expand them. However, it is necessary to do both. This requires using pricing strategies (low fares supported by adequate subsidies) to encourage the effective use of existing conventional public transport systems. It also requires using transport technologies such as paratransit to enable groups such as the poorest, the elderly, the handicapped and disabled, and the disadvantaged to increase their ability to access jobs, social services and so on.

• Preserve and enhance the mobility opportunities available to the general population.

The mobility opportunities available today to the general population of most developed-world countries (and in many developing-world countries) greatly exceed those of any period in the past. However, the changes in urban living patterns that have been noted above as adversely impacting the mobility opportunities of the poorest, the elderly, the handicapped, and disabled, and the disadvantaged also threaten to erode the mobility opportunities of many average citizens. In particular, the ability of conventional public transport systems to perform their vital role in providing personal mobility is being threatened.

During the next several decades, a primary goal should be to preserve these mobility options. At the same time, new mobility systems that could be sustainable in a future urbanized/ suburbanized world need to be developed and their implementation begun.

In many urban areas in both developed and developing countries the SMP believes that there are important opportunities for increased utilization of bus and "bus-like" systems (including paratransit) to take advantage of the flexibility inherent in road-based systems. Advantage should also be taken of opportunities to incorporate new vehicle technologies (including propulsion systems) and new information technologies into these "bus-like" systems. There is important potential for new patterns of vehicle ownership and use (such as car sharing) to become integral parts of the mobility systems of many areas.

Over the very long run - five decades or more – societies face a fundamental choice about how their mobility patterns will develop. Some hold that in order to make mobility sustainable, people will have to be induced to live in significantly more dense agglomerations. According to this view, only by doing this will it be technologically and financial feasible to rely on public transport to a much greater degree than is generally the case today. To produce this change in living patterns, different forms of "carrots" (urban planning aimed at making such patterns more desirable) and "sticks" (making motor vehicle ownership much more expensive and complex) will be necessary.

To us, this strategy seems to rest on forcing people to adapt to the technological and economic characteristics of transport systems. An alternative strategy is to adapt the technological and economic characteristics of transport systems to fit the living choices of the public. The various vehicle technologies we have described appear to have the potential to enable such an adaptation. But, as with other applications of these technologies, translating this potential into reality will require a great deal of work by a large number of stakeholders.

V.

The roles of "building blocks," "levers" and "institutional frameworks" in achieving the above goals

In our report we define a "building block" as something that has the potential to generate change if it can be utilized effectively. The building blocks we concentrate most heavily on in our report are vehicle technologies and fuels, but there are others. However, building blocks cannot act by themselves. To move, they require the use of "levers." These are either policy instruments such as pricing, voluntary agreements, regulation, subsidies, taxes and incentives or they are changes in a society's underlying attitudes, and values. In the body of the report we describe some of these levers and what we know about their effectiveness.

However, there is a third element - "institutional frameworks." These are the economic, social, and political institutions that characterize a particular society. We have mentioned these already – e.g., in our discussions of differences in the willingness of different societies to accept "intrusive" traffic safety enforcement policies such as speed cameras and self-reporting by vehicles to regulatory authorities that they are emitting illegal levels of conventional pollutants. But as we end this Overview, we want to focus more on this vital third elements.

Why worry about institutional frameworks? "Institutions are the rules of the game in a society or, more formally, are the humanly devised constraints that shape human interaction... In consequence, they structure incentives in human exchange, whether political, social, or economic." *(North 1990)*. In our specific context, institutions establish the context by which a country or region determines which sustainable mobility goals to pursue and the priority given to each; which levers are acceptable to use to achieve any particular goal; how intensively these levers can be used; and the constraints that may be imposed on their use.

Institutional frameworks influence a society's mobility choices in many ways: They affect the time and effort required to reach consensus about whether to address a particular issue and how aggressively to address it. They affect the ability of a government to formulate long-term approaches and the credibility of its commitments. They affect the instruments that governments use to enforce a society's laws and norms as well as the ways in which these instruments are used. They affect whether a government can or will undertake policies and approaches whose success requires joint action and agreement with other governments. They determine the social acceptability of certain products and services as well as the social acceptability of different patterns of product use and the range of different patterns that are tolerated. They affect the apportionment of responsibility and cost within society to achieve a desired result. They encourage or discourage voluntary collaboration across a range of stakeholders.

In short, they determine whether and how sustainable mobility will be achieved.

Achieving sustainable mobility is almost certain to require changes in personal and goods transport systems and in how society uses them. The size and type of changes that may be needed may put great pressure on some societies' political, cultural, and economic institutions. For example: Some approaches might require governments to impose policies that previously had been thought to be impractical or politically unacceptable. Some might require governments to make extremely long-term (more than 50 years) commitments. Some might require the public to accept levels of government intrusiveness regarding vehicle use that in the past have been considered unacceptable. Some might require governments to undertake types and levels of spending – for example, on infrastructure – that previously had been considered unconventional or objectionable. Some might require segments of the population to be favored relative to other segments. Some might require certain societies to accept restrictions on long-standing legal rights. Some might require certain societies to cooperate with other societies in ways that had previously been deemed unacceptable. Some might significantly impact (or preclude) traditional patterns of purchase and use of certain products.

There is no guarantee that different societies will be able (or willing) to undergo these changes. When a society encounters a mismatch between a goal it has declared important and its willingness (or ability) to employ the levers that might be needed to achieve that goal, it faces a dilemma. It can declare certain policies or efforts to change behavior to be "unthinkable," thereby effectively (if not actually) abandoning achievement of the goal. It can risk adopting policies that are "difficult" for various groups to accept and try to encourage (or force) acceptance after the fact. It can try to change the acceptability of certain policies prior to adopting them through publicity, broad stakeholder involvement in their design, or agreeing to compensate actual or perceived "losers."

Moving towards sustainable mobility will involve paying as much attention to institutional frameworks as to the inherent potential of any vehicle technology or fuel or the theoretical "effectiveness" or "ineffectiveness" of any particular policy lever or action.

VI.

How companies like ours can contribute to achieving the goals we have identified

Most of the issues described in our report are not new to our companies. As the report indicates, we have made considerable progress in providing the fuels and vehicles to control transport-related conventional emissions and are within sight of eliminating these concerns in the developed world. All our companies are involved in programmes to address road safety issues, whether through active safety systems in vehicles, through driver training programmes in schools and elsewhere, and through a wide variety of education programmes encompassing drivers, passengers and pedestrians.

The picture on greenhouse gases is more complex as we move to reduce not only the emissions from our own operations, but also the much more challenging task of those arising from the use of our products -- fuels and vehicles -- by our customers. The fundamental aim is to reduce fuel consumption of our products while working to develop the future fuels and vehicles that will provide for a carbon neutral outcome. This is an area of both competition and collaboration, but our companies are involved, for example, in joint initiatives such as the California Fuel Cell Partnership and in demonstration projects with hydrogen and fuel cell vehicles in both developed and developing countries.

The extreme importance of transport to our societies and the fact that transport-related considerations have some impact on almost everything done within them means that our ability to act independently in many areas is extremely limited.

Regarding the control of conventional emissions, we can continue to improve the effectiveness and reliability of the emissions control equipment in our vehicles. We can encourage aggressive efforts to detect "high emitters" and to require these vehicles to be fixed or removed from service. In the developing world, we can strive to reduce the cost of emissions control equipment and increase the "robustness" of this equipment to poor maintenance and poor quality fuels. We also can work to reduce the additional cost and to increase the availability of the necessary fuels. We cannot force our customers to maintain their vehicles properly or to scrap their older, more polluting vehicles and replace them with newer, less polluting ones. That is something that only governments can do. And in determining whether or not to do so, governments must consider more factors than merely the effectiveness of emissions control.

Our role in achieving the goal of reducing transport-related GHGs to

sustainable levels is also limited. We can and will continue to improve mainstream technologies and develop and implement new technologies. However, from a business perspective, we cannot justify production of vehicles that customers won't buy or produce and distribute fuels for which there is little or no demand. If the costs of the vehicles and fuels required to reduce GHG emissions from road vehicles are greater than our customers are willing to pay, and if society requires action to be taken, then it is up to governments to provide the necessary incentives, either to us or to our customers, to permit us to make these vehicles and fuels available. We can engage in the public debate, encourage governments to adopt such incentives, and help them understand which will and won't be effective. As far as advanced technologies and fuels are concerned, we can work together and with governments to increase understanding of what is technically feasible and work to reduce the technological and economic uncertainties described in detail earlier in this report.

Regarding road safety, we can support the adoption of appropriate, effective safety-related vehicle technologies. We can encourage more aggressive enforcement of traffic laws. We can undertake programs to educate motorists about how to operate their vehicles more safely and vulnerable users about how protect themselves. We can support the construction of infrastructure designed to separate motorized vehicles from vulnerable users and to encourage vehicle speeds appropriate to road and location conditions. However, in many cases, the safety consequences of how our products are used by our customers are even less subject to our control than are the emissions consequences.

The most extreme example of where we have limited leverage is in narrowing the mobility opportunity divides described above. We can support efforts by the World Bank and other institutions to provide basic road access for individuals living in rural regions of the poorest countries. However, we cannot provide these roads ourselves. We can support efforts to encourage new approaches to providing improved mobility opportunities in urbanized areas (e.g., car sharing, paratransit, and new mobility systems). However, we have little influence over whether societies will choose to adopt such approaches or whether they will be successful if adopted.

VII.

The way forward

By collaborating on this project, our companies have advanced their own understanding of the key areas to be addressed in moving towards more sustainable patterns of mobility, a much better sense of where the solutions lie, and what needs to be done to deliver them.

An important purpose of this report is to be a catalyst for advancing the sustainable mobility agenda within the companies. And in reviewing the conclusions of their work prior to publication of the report, the companies have looked at what could be done to accelerate progress on the goals beyond the extensive and diverse activities on which they are already engaged. There are clearly opportunities, but they must sensibly be the result of wider consultation both within the companies and with others. We therefore need to debate both internally and with a range of stakeholders to determine where and how best to focus our activity. This we are committed to do because we recognize both the imperative and the opportunity that the report sets out. The goals clearly set out the focus for attention and recognize the variety of timescales and choices to be considered.

In addition to the report itself, we are making available the underpinning work and material from which the report is drawn, including the scenarios we used to help guide our efforts. (These scenarios are described briefly at the end of Chapter 2 of our report.) We also are making available the spreadsheet model and explanatory documentation which was developed jointly with the IEA. This will we believe provide a basis for others to initiate further work.

As the CEO's of the companies point out in our report's Foreword, enhanced mobility is critical to progress, but can bring with it a set of impacts that must be resolved. Much has been achieved and we are now developing a clearer understanding of how better to resolve the issues leading to more sustainable mobility. For us, and we hope for others, the work of this project will be an important contribution, and we anticipate working with others to deliver the progress that is clearly possible.

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Glossary of terms; list of abbreviations and acronyms

Bar – A unit of measure of atmospheric pressure; equals 14.5 lbs/square inch.

Biodiesel – A fuel produced from vegetable oils. Also known as Fatty Acid Methyl Esters (FAME).

Biofuels – Fuels produced from biomass crops such as corn, soybeans, sugar, poplar, willow and switchgrass; from agricultural waste and forestry residues; and from landfill gas and municipal solid waste.

Carbon neutral – Emitting no net carbon into the atmosphere.

Carbon sequestration – The addition of a carbon-containing substance (such as CO_2) to a reservoir.

CONCAWE – Conservation of Clean Air and Water in Europe

Conventional pollutants – Generally used to refer to emissions of carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM), sulfur oxides (SOx), and unburned hydrocarbons (HC). The latter are sometimes also referred to as volatile organic compounds (VOCs) or non-methyl organic gases (NMOG).

Electrochemical – The production of electricity by chemical changes.

Ethanol (C_2H_5OH) – A clear, colorless, flammable oxygenated hydrocarbon.

EUCAR – The European Council for Automotive Research & Development

EU-15 – The 15 members of the European Union prior to its 2004 enlargement.

EU-25 – EU-15 plus the ten countries joining the EU in 2004.

Feedstock logistics – The gathering of raw materials for the production of fuel.

F-T diesel – A liquid fuel manufactured from natural gas using the Fischer-Tropsch process; used in compression-ignition engines.

F-T gasoline – A liquid fuel manufactured from natural gas using the Fischer-Tropsch process; used in spark-ignition engines.

Fuel cell – An electrochemical device that continuously changes the chemical energy of a fuel (hydrogen) and oxidant (oxygen) directly to electrical energy and heat without combustion.

Fuel infrastructure – Systems for distributing fuel from its point of production to where it is put into a transport vehicle.

GHGs -- Greenhouse gases – Primarily water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3).

Harsh road environments – Operating conditions in which roads are unpaved, poorly maintained, and/or little more than trails.

Heavy road vehicles – Generally, freight trucks larger than small delivery vans (i.e., medium-duty and heavy-duty trucks), intercity buses, and public transport buses.

HEV – Hybrid-electric Vehicle

High emitter – A vehicle emitting a much greater volume of "conventional" pollutants than permitted by the emissions standard(s) to which it was certified.

Hybridization – The process of using multiple propulsion devices (e.g., a spark ignition engine and one or more electric motors) to propel a vehicle.

Intelligent transport systems (ITS) – Transport vehicles and infrastructure that incorporate a broad range of wireless and wired communications-based information, control and electronics technologies to help monitor and manage traffic flow, reduce congestion, provide alternate routes to travellers, etc.

IEA – International Energy Agency

Light duty vehicle – Passenger cars and other light personal-use vehicles. Does not generally cover powered two and three-wheelers.

Lignocellulosic material – Any of various compounds of lignin and cellulose comprising the essential part of woody cell walls of plants.

Methanol (CH_3OH) – A colorless highly toxic hydrocarbon.

Natural gas – A mixture of hydrocarbon compounds, primarily methane (CH_4), that exist in the gaseous phase or in solution with crude oil in natural underground reservoirs at reservoir conditions.

Noise barriers – Structures constructed adjacent to a road, railway line, or airport to reduce noise from transport vehicles using the facility.

Paratransit – All forms of public and private mass transportation in the spectrum between the private automobile and conventional public transport.

Powered 2 and 3 wheeler – A two or three-wheeled vehicle powered by some form of motor or engine. Includes motorcycles and scooters.

Residual Fuel – Heavy petroleum products used to power large ships.

Rolling resistance -- A measure of the amount of resistance that is generated as a tire rolls on the road surface.

SUV – Sport Utility Vehicle

Steam methane reforming – A process by which steam at a temperature of 700-1,100 °C is mixed with methane gas in a reactor with a catalyser at 3-25 bar pressure.

Water electrolysis – The production of hydrogen from water using electricity.

WTW – Well-to-Wheels – A method of measuring GHG emissions that includes both emissions resulting from the extraction, production, and distribution of transport fuels (referred to as Well-to-Tank, or WTT) and emissions resulting from the use of the fuel by the vehicle (referred to as Tank-to-Wheels, or TTW.)

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About the WBCSD

The World Business Council for Sustainable Development (WBCSD) is a coalition of 170 international companies united by a shared commitment to sustainable development via the three pillars of economic growth, ecological balance and social progress.

Our members are drawn from more than 35 countries and 30 major industrial sectors. We also benefit from a global network of 50 national and regional business councils and partner organizations involving some 1,000 business leaders.

Our mission

To provide business leadership as a catalyst for change toward sustainable development, and to promote the role of eco-efficiency, innovation and corporate social responsibility.

Our aims

Our objectives and strategic directions, based on this dedication, include:

Business leadership

> to be the leading business advocate on issues connected with sustainable development

Policy development

> to participate in policy development in order to create a framework that allows business to contribute effectively to sustainable development

Best practice

> to demonstrate business progress in environmental and resource management and corporate social responsibility and to share leading-edge practices among our members

Global outreach

> to contribute to a sustainable future for developing nations and nations in transition

What is the Sustainable Mobility Project

The Sustainable Mobility Project is a member- led project of the World Business Council for Sustainable Development (http://www.wbcsd.org). The project develops a global vision covering the sustainable mobility of people, goods and services in road transport. The project shows possible pathways towards achieving sustainable mobility that will address environmental and economic concerns if society is prepared to recognize the issues and act upon them.

Disclaimer

Mobility 2030 has resulted from collaborative work among executives from the twelve member companies of the WBCSD's Sustainable Mobility Project, sponsored by the WBCSD as a member-led initiative and supported by the WBCSD secretariat. Like other WBCSD projects, the SMP has involved extensive stakeholder engagement in locations around the world. Prepared with the help of Charles River Associates and several other consultants, the report was reviewed by all project members to ensure broad general agreement with its principal views and perspectives. However, while a commendable level of consensus has been achieved, this does not mean that every member company necessarily endorses or agrees with every statement in the report.

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