

## EXECUTIVE SUMMARY

### Overview

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Transport accounts for about 19% of global energy use and 23% of energy-related carbon dioxide (CO<sub>2</sub>) emissions and these shares will likely rise in the future. Given current trends, transport energy use and CO<sub>2</sub> emissions are projected to increase by nearly 50% by 2030 and more than 80% by 2050.

This future is not sustainable. The Intergovernmental Panel on Climate Change (IPCC) advises that, to avoid the worst impacts from climate change, global CO<sub>2</sub> emissions must be cut by at least 50% by 2050. To achieve this, transport will have to play a significant role. Even with deep cuts in CO<sub>2</sub> from all other energy sectors, if transport does not reduce CO<sub>2</sub> emissions well below current levels by 2050, it will be very difficult to meet targets such as stabilising the concentration of greenhouse gas (GHG) emissions in the atmosphere at a level of 450 ppm of CO<sub>2</sub> equivalent.

Substantially changing transport trends will require both the widespread adoption of current best available technology, and the longer-term development and deployment of a range of new technologies. It will also require strong policies to ensure rapid uptake and full utilisation of these technologies, and to encourage sensible changes in travel patterns. It will involve industry, governments and consumers. This book shows a clear pathway for achieving a low CO<sub>2</sub>, sustainable transport future.

All transport modes will need to reduce their emissions significantly compared to the Baseline trends, in every region of the world. This publication shows how the introduction and widespread adoption of new vehicle technologies and fuels, along with some shifting in passenger and freight transport to more efficient modes, can result in a 40% reduction in CO<sub>2</sub> emissions below 2005 levels. As outlined in the IEA publication *Energy Technology Perspectives 2008* (ETP 2008), such emission reductions in transport can be consistent with a goal to reduce total global energy-related CO<sub>2</sub> emissions in 2050 by 50% from current levels, since greater emission reductions are possible in some other sectors. Further, much of the transport CO<sub>2</sub> reductions can probably be achieved at a low overall cost to society, with costs for advanced technologies reducing over time, as a result of learning from increasing production and use. However to achieve the targets, marginal costs up to USD 200 per tonne of CO<sub>2</sub> saved, or even higher, may be unavoidable.

The benefits of strong decarbonisation in transport also extend to energy security. Transport oil use can be cut by more than half in 2050 compared to today's level, vastly increasing the likely stability and security of supplies. Energy carriers such as hydrogen (H<sub>2</sub>) and electricity also have far better energy security characteristics, since they can be produced from a wide range of primary energy sources rather than just oil. Additionally, in many cases a significant fraction of these primary energy sources can be obtained within the countries and regions that consume them.

## A sustainable pathway for transport

Current and emerging technologies have the potential to deliver substantial reductions in CO<sub>2</sub> emissions from transport. But they need to be introduced rapidly, at a rate and on a scale that is unprecedented in the last 40 years of transport evolution. Which new technologies will ultimately show the most promise is still uncertain, as is the contribution that could be achieved from travel shifts to more efficient modes. This publication therefore uses a number of Baseline and CO<sub>2</sub> abatement scenarios to examine these issues.

### Box ES.1 ► Scenarios considered in this study

*This analysis uses the same basic set of scenarios originally developed for the ETP 2008 publication. These cover various futures through 2050, including a Baseline and several ways to achieve very low CO<sub>2</sub> emissions for transport. Specific scenarios include:*

**Baseline:** follows the IEA World Energy Outlook 2008 (WEO 2008) Reference Case to 2030 and then extends it to 2050. It reflects current and expected future trends in the absence of new policies.

**High Baseline:** this scenario considers the possibility of higher growth rates in car ownership, aviation and freight travel over the period to 2050 than occur in the Baseline.

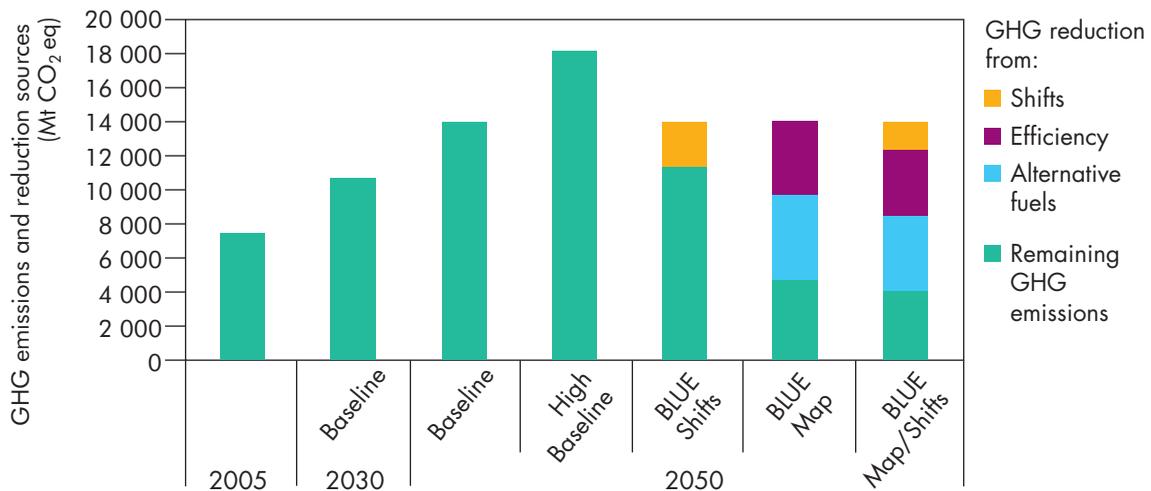
**BLUE CO<sub>2</sub> reduction scenarios:** these scenarios update those presented in the IEA Energy Technology Perspectives 2008 report. The BLUE variant scenarios are developed based on achieving the maximum CO<sub>2</sub> reduction in transport by 2050 using measures costing up to USD 200 per tonne. These scenarios will require strong policies to be achieved.

- **BLUE Map:** this scenario achieves CO<sub>2</sub> emissions by 2050 that are 30% below 2005 levels. It does this via strong improvements in vehicle efficiency and introduction of advanced technologies and fuels such as plug-in hybrids (PHEVs), electric vehicles (EVs), and fuel cell vehicles (FCVs). It does not envisage significant changes in travel patterns.
- **BLUE EV Success:** Similar to BLUE Map and achieving a similar CO<sub>2</sub> reduction, but with electric and plug-in hybrid vehicles achieving greater cost reductions and better performance to the point where they dominate light-duty vehicle (LDV) sales by 2050, to the exclusion of fuel cell vehicles.
- **BLUE Shifts:** this scenario focuses on the potential of modal shift to cut energy use and CO<sub>2</sub> emissions. Air and LDV travel grow by 25% less than in the Baseline to 2050, and trucking by 50% less. The travel is shifted to more efficient modes and (for passenger travel) to some extent eliminated via better land-use planning, greater use of information technology, and other measures that reduce the need for motorised travel. Compared to the Baseline in 2050, BLUE Shifts results in a 20% reduction in energy use and CO<sub>2</sub>.
- **BLUE Map/Shifts:** this scenario combines the BLUE Map and BLUE Shifts scenarios, gaining CO<sub>2</sub> reductions from efficiency improvements, new vehicle and fuel technologies, and modal shift. It results in a 40% reduction in CO<sub>2</sub> below 2005 levels by 2050.

## The BLUE Map scenario

The BLUE Map scenario is the “foundation” scenario for this study. It shows that a 30% reduction in transport CO<sub>2</sub> emission in 2050 compared to 2005 can be achieved by the uptake of technologies and alternative fuels across all transport modes that cost less than USD 200 per tonne of CO<sub>2</sub> saved. Under this scenario, improvements in transport energy efficiency offer the largest and least expensive CO<sub>2</sub> reductions, at least over the next ten years. Adoption of advanced vehicle technologies and new fuels also provides important contributions to this scenario, especially after 2020. The impacts in terms of CO<sub>2</sub> reductions in 2050 (along with those for other scenarios) are shown in Figure ES-1.

**Figure ES-1** ► Summary of GHG reductions by scenario in this study<sup>1</sup>



### Key point

Transport sector GHG emissions in BLUE Map/Shifts are 40% below 2005 levels.

## Vehicle efficiency improvements in BLUE Map

A principal finding of the BLUE Map analysis is that the implementation of incremental fuel economy technologies could cost-effectively cut the fuel use and CO<sub>2</sub> emissions per kilometre of new light-duty vehicles (LDVs) worldwide by 30% by 2020 and 50% by 2030. Similar efficiency improvements may be possible for other modes, although the estimation of technology potentials for trucks, ships and aircraft is not as accurate as it is for LDVs in this analysis. Further, many of the available improvements for these modes are expected to occur in the Baseline scenario, which includes improvements of 20% to 25% by 2050. But the achievement of a 30% to 50% reduction in fuel use per kilometre travelled for trucks, ships and aircraft by 2050 appears possible. For all modes and types of vehicles, the identification and

1. In this figure, and throughout this study except where noted, greenhouse gases include CO<sub>2</sub> emissions from vehicles, and CO<sub>2</sub>, methane and nitrogen oxide emissions from fuel production. It does not include other GHGs, such as water vapour from aircraft or sulphur oxide from shipping.

setting of efficiency targets for the 2020-30 timeframe would be valuable to help stimulate and co-ordinate action, particularly if backed up by the development of policies around the world to help achieve these targets.

A 30% to 50% improvement in new vehicle efficiency across modes by 2030 would help to achieve a stock average improvement of a similar magnitude by 2050. In the BLUE Map scenario, this cuts transport energy use and CO<sub>2</sub> enough to just about stabilise it at 2005 levels. To go well below 2005 levels, switching to new low-CO<sub>2</sub> fuels, along with travel and modal shift policies, will need to play increasingly important roles.

## Alternative fuels in BLUE Map

In the Baseline scenario, petroleum-based fuels continue to account for about 90% of all transport fuel in 2050. In the High Baseline, an increasing share of very high CO<sub>2</sub> fuels, such as coal-to-liquids, increases CO<sub>2</sub> emissions even faster than fuel use. In contrast, in the BLUE Map scenario, the share of petroleum and other fossil fuels falls to below 50%. They are replaced by a combination of advanced, low CO<sub>2</sub> biofuels, electricity and hydrogen. If produced from low CO<sub>2</sub> feedstocks, any one of these options might be sufficient to achieve the outcomes envisaged, but each also has drawbacks and may not reach its full potential. A combination of these can maximise the chances of overall success, even if it would result in higher investment costs to develop adequate production and distribution infrastructures. Pursuing a combination, at least in the initial stage, appears to be a wise choice to maximise the potential benefits without locking-out potential solutions.

Ethanol from sugar cane can already provide low-cost biofuels, and increasingly does. Advanced (second-generation) biofuels, such as ligno-cellulosic ethanol and biodiesel derived from biomass (biomass to liquids), appear to have the best long-term potential to provide sustainable, low life-cycle GHG fuels, but more research, development and demonstration (RD&D) will be needed before commercial scale production is likely to occur. For all biofuels, important sustainability questions must be resolved, such as the impact of production on food security and sensitive ecosystems as a result of land-use change. About a 20-fold increase in biofuels is needed to achieve the outcomes envisaged in the BLUE Map scenario by 2050. If done wisely, this should be possible using only a small share of global agricultural land.

## Advanced vehicle technologies in BLUE Map

EVs, PHEVs, and FCVs all play an important role in BLUE map, especially after 2020. EVs are rapidly emerging as an important option, especially as lithium-ion battery costs decline. It now appears that batteries for a pure electric vehicle, in high-volume production, might cost as little as USD 500/kWh in the near term, low enough to bring the battery cost for a vehicle with a 150 km range down to about USD 15 000. This is still very expensive. But with savings from removing the internal combustion engine, and with relatively low-cost electricity as the fuel, this might be sufficient to allow EVs to achieve commercial success over the next five to ten years, if coupled with policy assistance such as support for the development of an appropriate recharging infrastructure. The cost of oil, the principal competing fuel,

will also be an important factor. Since the impact of EVs on CO<sub>2</sub> emissions depends on the CO<sub>2</sub> intensity of electricity generation, it would make sense to deploy EVs first in those regions with already low CO<sub>2</sub> generation or a firm commitment to move in that direction. This would include Japan, the European Union, and parts of North and South America.

A potentially important transition step to EVs is offered by PHEVs. By increasing the battery storage in hybrid vehicles and offering a plug-in option, these vehicles represent an important step toward vehicle electrification that builds incrementally on an emerging hybrid vehicle technology. Like hybrids, PHEVs use both engine and motor, which adds cost. But the advantage of PHEVs lies in providing a potentially significant share of driving on electricity with a small, and therefore relatively inexpensive, battery pack. For example, an 8 kWh battery pack might cost USD 5 000 to USD 6 000 in the near term and provide 40 kilometres of driving range on electricity. For many drivers, running most of the first 40 kilometres per day on electricity could cut oil use dramatically, by 50% or more in some cases. PHEVs may also require less new infrastructure than pure EVs since the car is not dependent solely on electricity and has a full driving range on liquid fuel.

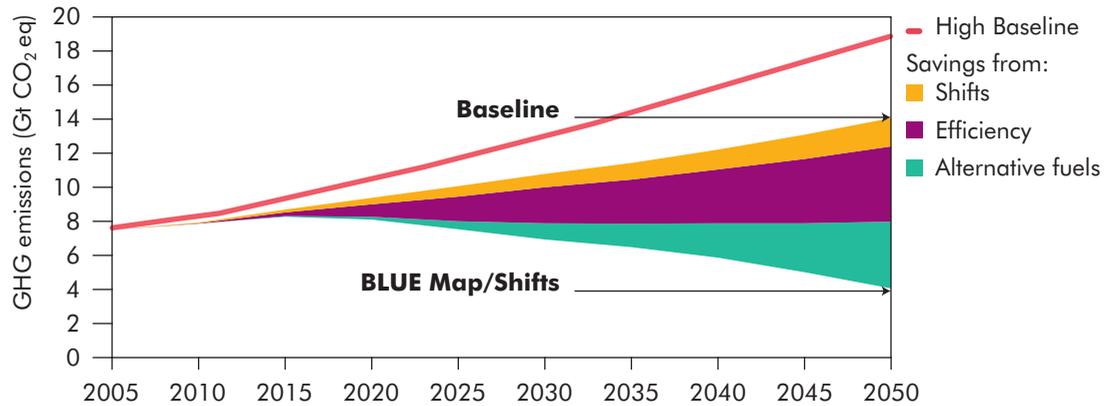
In the BLUE Map scenario, both EVs and PHEVs are initially deployed in 2010 and increase in sales to well over one million per year by 2020. EVs and PHEVs experience rapid market penetration around the world, each reaching annual sales of around 50 million by 2050, primarily as passenger LDVs but also a small share of trucks. The widespread introduction of EVs illustrated in the BLUE Map scenario requires adequate investments and co-ordination amongst governments and industry for the development of recharging infrastructure for EVs. In a separate scenario called BLUE EV Success, in which EVs almost fully dominate LDV sales by 2050 (essentially displacing FCVs), their sales exceed 100 million per year.

Hydrogen fuel cell vehicles also play a key role in the BLUE Map scenario. FCVs co-exist with EVs and are produced commercially beginning around 2020. They reach a significant sales share by 2030, with sales then rising rapidly to nearly 60 million by 2050. Recent cost reductions in fuel cell systems for vehicles increase the likelihood that FCVs can eventually become commercialised, although costs and on-board energy storage are still important concerns. As battery costs drop, hybridising fuel cells appears increasingly attractive, since batteries can help provide peak power to the motor, allow a smaller fuel cell stack to be used, and improve efficiency through regenerative braking. The development of a hydrogen production and distribution infrastructure is necessary, and will require substantial new investments if hydrogen becomes used on a large scale. Like electricity, H<sub>2</sub> must be produced with low CO<sub>2</sub> technologies in order for FCVs to provide significant CO<sub>2</sub> reductions. This will result in higher hydrogen costs than if it were produced from, for example, reforming natural gas.

## The BLUE Shifts scenario

Beyond changes to future vehicles and fuels, shifts in some passenger travel and freight transport to more efficient modes can also play an important role in reducing energy use and CO<sub>2</sub> emissions. Certainly from the point of view of cities around the world, developing in a manner that minimises reliance on private motorised travel

**Figure ES-2** ▶ Contribution of emissions reduction options in BLUE Map/Shifts Scenario, 2005-50



#### Key point

A 10 Gt reduction in GHG can be achieved by 2050 via modal shift, efficiency and alternative fuels.

should be a high priority given the strong co-benefits in terms of reduced traffic congestion, lower pollutant emissions and general liveability.

The BLUE Shifts scenario considers one possible future modal mix, in contrast to that implied in the Baseline, mainly in order to illustrate the potential energy and CO<sub>2</sub> reductions that could result.<sup>2</sup> It envisages an average worldwide reduction in private LDV and aviation passenger travel of 25% by 2050 relative to the Baseline scenario, and up to a 50% reduction compared to the High Baseline scenario (Figure ES-1). In addition, it includes a shift in freight movement to rail transport, which cuts long-haul truck transport growth between 2010 and 2050 by half. By shifting travel and goods transport to advanced bus and rail systems, along with some outright reductions in travel growth due to better land-use planning and improved non-motorised transport infrastructure, along with some telecommunications substitution for travel, about a 20% reduction in energy use appears feasible by 2050 compared to the Baseline, or about a 40% reduction compared to the High Baseline scenario. Even more ambitious mode shifting may be possible, but it will require strong policies and political will.

## The BLUE Map/Shifts scenario

Overall, with the efficiency, low-GHG fuels and advanced vehicles, and modal shift taken together, in the BLUE Map/Shifts scenario CO<sub>2</sub> emissions in transport are cut by 40% in 2050 compared to 2005, and by 70% compared to the Baseline in 2050 (Figure ES-2). This represents a 10 gigatonne (Gt) reduction from the 14 Gt that would otherwise be emitted by the transport system in 2050 in the Baseline and a 14 Gt reduction compared to the 18 Gt in the High Baseline. After 2050,

2. This scenario relies on more uncertain information in comparison to other sections of the analysis. It has been developed to provide a basis for estimating the potential energy and CO<sub>2</sub> impacts of modal shifts, and it will be refined further in the future.

further modal shifting and efficiency improvements, and the deeper penetration of low CO<sub>2</sub> alternative fuels, will be needed to keep transport on a downward CO<sub>2</sub> trend.

It will be extremely challenging for transport to achieve the outcomes implicit in the BLUE Map/Shifts scenario. Very strong policies will be needed, both to encourage development and implementation of alternatives, and to encourage consumers and businesses to embrace these alternatives. The following sections outline the contribution from the different modes and the policies that will be needed.

## Modal findings and policy considerations

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The four most important modes, in terms of their expected contribution to CO<sub>2</sub> in the Baseline scenario in 2050, are LDVs (43%), trucks (21%), aviation (20%) and shipping (8%). In the BLUE Shifts scenario, the role for buses and rail increases significantly and CO<sub>2</sub> reductions via efficiency and alternative fuels in these modes become increasingly important, though they are already quite efficient and likely to become more so.

### Light-duty vehicles

Car, sport utility vehicle (SUV) and passenger light-truck ownership around the world is expected to rise mainly as a function of income. In the Baseline scenario, the total stock increases from about 700 million in 2005 to nearly 2 billion by 2050. In the High Baseline scenario, car ownership rates rise even faster (with ownership more closely tracking the historical rates observed in the OECD Europe and Japan for a given income level), and reach nearly 3 billion. One obvious impact of this growth is a similar increase in the rate of fuel use, unless vehicles become far more efficient than they are today. Modal shifts to mass transit, walking and cycling, as well as long-distance bus and rail systems could also help a great deal, resulting in fewer cars but also encouraging people to use alternatives to their cars more often.

A 50% reduction in fuel use per kilometre for average new LDVs around the world by 2030, from incremental technology improvements and hybridisation, is possible and is likely to be cost effective even at relatively low oil prices. Net negative CO<sub>2</sub> reduction costs are achievable at least for much of this improvement. But it will be important that the efficiency gains are not simply offset by trends toward ever larger, heavier and faster cars. Policies will be needed both to ensure maximum uptake of efficiency technologies and to translate their benefits into fuel economy improvement. Fuel economy standards perhaps complemented by CO<sub>2</sub>-based vehicle registration fees can, and already do, play an important role around the OECD. It is important that non-OECD countries also adopt similar policies, and that all countries continue to update these policies in the future, rather than letting policies expire or stagnate. The Global Fuel Economy Initiative, in which the IEA is a partner, is focused on helping to achieve such outcomes.

Advanced technology vehicles will also play a key role, especially after 2020. Initiatives to promote EVs and PHEVs, and the continuing development of FCVs, will be extremely important. For governments, orchestrating the co-development of vehicle and battery production, recharging infrastructure, and providing incentives to ensure sufficient consumer demand to support market growth, will be a significant near-term challenge. Selecting certain regions or metropolitan areas to work with initially, that are keen to be early adopters, may be an effective approach.

Biofuels for LDVs, as well as for other modes, will play a role over time. Fuel compatibility with vehicles is not likely to be a significant problem, needing only minor modifications to new vehicles in the future. But a transition is needed to much more sustainable feedstocks and approaches to biofuels production. As sustainability criteria and rating systems emerge, policies need to shift toward incentivising the most sustainable, low-GHG, and cost-efficient biofuels while minimising impacts from land-use change. A transition to second-generation fuels from non-food feedstocks will play a key role. This is particularly true in OECD countries, as their current biofuels production is dominated by ethanol from grain crops and biodiesel from oil-seed crops. These compete with food/feed supplies and do not perform well in terms of GHG cost-per-tonne or land-use efficiency.

Shifting passenger travel to more efficient modes such as urban rail and advanced bus systems can play an important role in cutting CO<sub>2</sub>. But often it provides many other important benefits, such as lower traffic congestion, lower pollutant emissions and more liveable cities. Policies need to focus on better urban design to cut the need for motorised travel, improving mass transit systems to make them much more attractive, and improving infrastructure to make it easier to walk and cycle for short trips. Rapidly growing cities in developing countries have the opportunity to move toward far less car-oriented development than has occurred in many cities in OECD countries. But it will take strong measures and political will, and support for alternative investment paradigms.

Figure ES-3 shows the role and estimated marginal cost of different technologies and fuels in contributing to CO<sub>2</sub> reductions from LDVs in the BLUE Map scenario in 2050 (modal shifts and non-LDV modes are not included here). These curves are inherently uncertain, and sensitive to small changes in assumptions.<sup>3</sup> They show the particular combination of technology and fuels options that are deployed in the BLUE Map scenario, but other combinations could also achieve the same or similar outcomes in terms of CO<sub>2</sub> reductions.

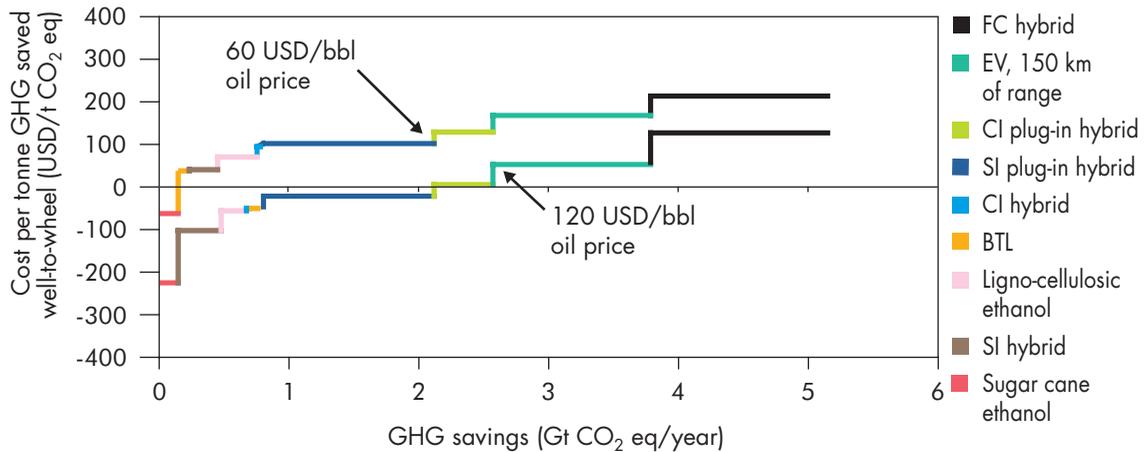
Despite the uncertainties, the results are revealing. By 2050, deep reductions in CO<sub>2</sub> equivalent GHG emissions from LDVs, on the order of 5 Gt, appear possible at a marginal cost of about USD 200/tonne with oil at USD 60/bbl. A second case, assuming a higher oil price of USD 120/bbl, is also shown. At this higher oil price, the emissions reductions are achieved at a marginal cost of about USD 130/tonne. Most of the emissions reduction is achieved at costs far below this. In earlier years, particularly up to 2030, most cost reductions come

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3. Costs in 2050 are particularly uncertain as they are partly dependent on earlier deployment, which triggers learning and cost reductions. Given the close position of various options in terms of cost per tonne, the "rank order" of different options could easily change. Further, options were selected on a wider set of criteria than just cost-minimisation, such as the portfolio benefit of deploying multiple low-GHG vehicle and fuel types.

from incremental improvements to internal combustion engine (ICE) vehicles and hybridisation, at very low average cost.

**Figure ES-3** ► **GHG reductions in BLUE Map for light-duty vehicles and fuels: contribution and estimated cost per tonne by vehicle and fuel type in 2050**



Note: SI = spark ignition (gasoline) vehicle; CI = compression ignition (diesel) vehicle; ICE = internal combustion engine vehicle; “hybrid” refers to hybrid-electric vehicle; BTL = biomass-to-liquids biodiesel; FC = fuel cell; EV= electric vehicle.

#### Key point

Substantial low-cost GHG reduction opportunities appear available, especially at higher oil prices.

## Trucks and freight movement

Trucking has been one of the fastest-growing modes in most countries over the past ten to 20 years. This growth is likely to continue in the future, although possibly with some decoupling from gross domestic product (GDP) as an increasing share of economic growth comes from information and other non-material sectors. Trucks have also become more efficient over time. But there remain major opportunities to improve efficiency still further, through technical measures, operational measures such as driver training, and logistical systems to improve the efficiency in the handling and routing of goods.

Through better technologies (such as advanced engines, light-weighting, improved aerodynamics, better tyres), new trucks can probably be made 30% to 40% more efficient by 2030. More information is needed on technology costs. But many of the improvements appear likely to be quite cost effective, perhaps reflecting more significant market failures in terms of truck operators adopting cost-effective technologies than is often believed. Logistic systems to ensure better use of trucks, and shifts to larger trucks in some cases, can provide additional efficiency gains system wide, and may also be quite cost effective. But to maximise the gains, governments will need to work with trucking companies, for example through supporting driver training programmes and to create incentives or requirements for

improved efficiency. Japan's Top-Runner Program efficiency requirements for trucks are the first of their kind in the world.

Trucks can use biodiesel fuel very easily, especially the very high quality biodiesel that comes from biomass gasification and liquefaction. Given that for many trucks shifting to electricity or hydrogen will be difficult, for example due to range requirements and energy storage limitations, the development of such second-generation biofuels may be the only way to substantially decarbonise trucking fuel.

Modal shift to rail continues to be an attractive option to save energy and cut CO<sub>2</sub> emissions, given the inherently efficient nature of rail. Many countries currently move only a small share of goods by rail. But to achieve shifts, very large investments in rail and intermodal systems will be necessary in most countries.

## Aviation

Air travel is expected to be the fastest-growing transport mode in the future, as it tends to grow even faster than income during normal economic cycles. Air passenger kilometres increase by a factor of four between 2005 and 2050 in the Baseline scenario, and by a factor of five in the High Baseline scenario. Aviation benefits from steady efficiency improvements in each generation of aircraft, and this is likely to continue. But given the expected very high rate of activity growth, aviation energy use and CO<sub>2</sub> emissions are expected to triple in the Baseline scenario and quadruple in the High Baseline scenario.

An increase in the rate of efficiency improvements beyond Baseline rates may be possible, by encouraging aircraft manufacturers to make bigger gains with each generation of aircraft and by improving air traffic control. A wide range of fuel efficiency technologies for aircraft remain unexploited, including aerodynamic improvements, weight reduction and engine efficiency, with an estimated overall potential to make average aircraft nearly twice as efficient in 2050 as they are today. Improved air traffic control can also improve the overall fuel efficiency of aviation. Savings are in the order of 5% to 10%. More work is needed better to understand the cost-effectiveness of various options, although a few available estimates suggest that some may be quite cost-effective. One significant factor in assessing technology cost-benefit for aircraft is that aircraft burn large quantities of fuel over their lifetimes; up to 1 billion litres of jet fuel for a very large aircraft. Thus, cutting fuel use can provide enormous fuel cost savings. This suggests that even major investments to improve aircraft efficiency may be cost-effective, at least using a long-term, societal cost perspective.

Measures to encourage faster introduction of new technologies on successive generations of aircraft, reflecting very high societal benefits, can help. This can also be promoted by international agreements that price or limit aviation GHG emissions. However, GHG reduction is complicated by the fact that CO<sub>2</sub> is just one of several aircraft emissions that have radiative forcing (i.e. climate warming) effects. Others include nitrogen oxides, methane, water vapour and cloud formation. Much more work is needed to better understand the net effects and optimal strategies for reducing overall aviation GHG emissions.

Even more than trucks, aircraft are restricted in the types of fuels they can use. The energy density of liquid fuels is critical for providing adequate aircraft flying range, so shifting to gaseous fuels or electricity appears impractical (liquid hydrogen may be a viable option, but requires major compromises in other airplane design features). Thus, high quality, high energy-density aviation biofuels are of great interest to airlines and aircraft manufacturers, as these may hold the best hope of providing low-GHG fuels in the future. But the concerns expressed above regarding biofuels sustainability and feedstock supply apply to aircraft as they do for other modes. In the BLUE Map scenario, 30% of aircraft fuel is second-generation biofuel, such as biomass-to-liquid (BTL) fuel, by 2050.

Modal shift and a general reduction in aviation travel growth can help. In the BLUE Shifts scenario, air travel growth is cut by 25%, resulting in a tripling by 2050 rather than quadrupling. This will, to some extent, occur naturally if alternatives such as high-speed rail systems are provided, but it must also be encouraged by policies that, for example, help ensure the availability and cost-competitiveness of rail travel. Substituting telematics (such as teleconferencing) for some long-distance trips could also play an important role, and could also be encouraged by governments as well as by businesses.

## Shipping

International water-borne shipping has grown very rapidly in recent years, in particular as a function of the growth in Asian manufacturing and exports to other countries. It now represents about 90% of all shipping energy use, the remainder being used in-country by river and coastal shipping. Container shipping fuel use has risen the fastest, and may rise much more in the future; projections of up to an 8-fold increase for container shipping to 2050 have been made. The average size of ships is also rising, such that shipping is becoming steadily more efficient per tonne-kilometre moved, although practical limits to ship size may be at hand.

Apart from size increases, ship efficiency has not clearly been improving significantly in recent years. The structure of the shipping industry – with fragmented and very different systems of ownership, operation and registration often all happening in different countries for a given ship – may serve to limit the market incentives to optimise ship efficiency.

Many potential efficiency improvement measures have been identified. About 50 are outlined in the shipping chapter of this publication. If most of these options were adopted, it is estimated that a 50% or greater reduction in energy use per tonne-kilometre could be achieved, even taking into account various interactions between options. More research on cost is needed, but recent research suggests that many options for retrofitting existing ships could achieve substantial energy and CO<sub>2</sub> savings at very low or net negative cost.

As for aircraft, biofuels hold important potential for decarbonisation of shipping fuel. Ship engines are capable of using a wide range of fuels, and may be able to use relatively low quality, low-cost biofuels. In the BLUE Map scenario, 30% of ship fuel by 2050 is low GHG biofuel.

Policies to promote improved international shipping efficiency and CO<sub>2</sub> reduction may have to come from international agreements. Shipping could be included in a CO<sub>2</sub> cap-and-trade system. Another proposal has been to develop a ship efficiency index, and to score all new and existing ships using the index. This could be coupled with international incentives or regulations on new ship efficiency and used to encourage modifications to existing ships, given that many efficiency retrofit opportunities are available. But more work is needed to develop such an index, in particular to estimate the efficiency benefits and costs for various types of improvements. The UN International Maritime Organisation (IMO) has a lead role in such efforts, although separate efforts are also needed to provide multiple viewpoints and sources of information.

## The role of international co-operation

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A significant reduction in CO<sub>2</sub> emissions in transport will only be possible if all world regions contribute. Although transport CO<sub>2</sub> per capita is far higher today in OECD than in non-OECD countries, nearly 90% of all the future CO<sub>2</sub> growth is expected to come from non-OECD countries. In the IEA BLUE scenarios, all regions cut transport CO<sub>2</sub> dramatically compared to the Baseline in 2050. Vehicles can be made much more efficient in all parts of the world, generating large fuel savings. Changes in travel can also occur, although in many countries the main priority needs to be to preserve current low-energy travel modes. Alternative fuels, if their costs can eventually approach those for oil-based fuels, will also be welcomed world wide.

Governments will need to work together – and with key stakeholders – to ensure that markets around the world send similar signals to consumers and manufacturers, in part to maximise efficiency and limit the cost of future changes. Common medium- and long-term targets in terms of fuel economy, alternative fuels use, and even modal shares would send clear signals to key players and help them begin to plan. For those producing efficient products, knowing that a wide range of markets will be eager for those products will help plan production and, through market size, cut costs. The Global Fuel Economy Initiative represents an important example of moving toward greater international co-operation in developing targets and standards.

In addition to setting and reaching efficiency targets, national governments need to work together and with key stakeholders to develop and deploy new types of very low-GHG vehicles and fuels. Technologies such as electric and fuel cell vehicles can only be introduced into markets in which there is adequate refuelling infrastructure, and consumers are willing and ready to purchase both the vehicles and the fuels. Markets alone will have difficulty achieving such outcomes. Governments must lead in orchestrating such transitions, and to help overcome the risks involved.

Most new technologies need government support while in the RD&D phase, before they become commercially viable. There is an urgent need for major acceleration in co-ordinated RD&D in breakthrough technologies. This needs to be coupled with the introduction of a range of policy measures that will create clear international targets and predictable, long-term economic incentives for new low-GHG technologies.

Roadmaps can help show what is needed to take technologies from their current status through to full commercialisation, and to outline the role of industries, governments and other stakeholders in achieving various outcomes. The IEA is developing energy technology roadmaps with broad international participation and in consultation with industry. These roadmaps will enable governments, industry and financial partners to identify the steps needed and co-operate to implement measures that will accelerate technology development and uptake. The IEA is currently completing a roadmap for electric and plug-in hybrid vehicles, and will launch other roadmaps in areas such as biofuels, advanced ICEs and fuel-cell vehicles in the near future.

## Conclusion

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This report shows that transport can achieve deep reductions in energy use and GHG emissions by 2050 through a combination of approaches, and with a mix of incremental and advanced technologies. In the long term, costs are expected to come down such that by 2050, the goals may be reached at a marginal cost of about USD 200 per tonne. But the transition to 2050 will include deploying some relatively high-cost options, and cost reductions are not assured. Strong RD&D programmes are needed to speed cost reductions and the market introduction of advanced technologies. These include electric and fuel cell vehicles, but also advanced designs for trucks, ships and aircraft; advanced, sustainable biofuels; and telematic and ITS systems to improve the efficiency of transport systems.

2050 is only 40 years away. To put transport on a sustainable pathway within that timeframe, current trends must be changed substantially within the next five to ten years. Strong policies are needed very soon to begin to shift long-term trajectories and to meet interim targets. While key long-term technologies such as advanced biofuels, electric and fuel cell vehicles are being developed and deployed, governments need to push hard for the efficiency of today's vehicles to be improved, and for the deployment of transition technologies such as plug-in hybrid vehicles. Strong measures are also needed in terms of investments in infrastructure and incentives that can influence how people choose to travel and enable much greater use of efficient modes. Many measures are already in place in different parts of the world. But stronger measures will be needed, and must be pursued with renewed vigour. Greater international co-operation can play a key role in sharing experience and overcoming obstacles to reaching sustainability.