Climate and Transportation Solutions:

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Chapter 2:

Scenarios for Cutting Carbon Dioxide in Transport 70 Percent Worldwide by 2050

by Lew Fulton

Worldwide, transport accounted for about 19 percent of global energy use and 23 percent of energy-related carbon dioxide (CO_2) emissions in 2006, and these shares will likely rise in the future. Given current trends, transport energy use and CO_2 emissions are projected to increase nearly 50 percent by 2030 and more than 80 percent by 2050.

This future is not sustainable. The United Nations Intergovernmental Panel on Climate Change (IPCC) advises that, to avoid the worst impacts from climate change, global CO_2 emissions must be cut at least in half by 2050. To achieve this, transport will have to play a significant role. Even with deep cuts from all other energy sectors, if transport does not cut CO_2 emissions well below current levels by 2050, it will be very difficult to meet targets, such as stabilizing the concentration of greenhouse gas (GHG) emissions in the atmosphere at a level of 450 parts per million (ppm) of CO_2 equivalents ($CO_{2\text{-eq}}$).

This paper develops analysis originally published in the International Energy Agency (IEA) *Energy Technology Perspectives 2008* (ETP 2008) and the forthcoming IEA report *Transport, Energy and CO_2: Moving Toward Sustainability* (IEA 2009). It describes 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 70 percent reduction in transport $CO_{2\text{-eq}}$ emissions in 2050 compared to the IEA baseline projection, which itself reflects a 40 percent reduction below 2005 levels. As part of a broader effort to cut emissions across the energy economy, this may be sufficient to help stabilize atmospheric CO_2 at average concentrations between 450 and 550 ppm and prevent temperature changes above 2° Celsius (C), according to the IPCC.

But substantially changing transport trends along the lines described here will not be easy. It will require both the widespread adoption of current best available technology and the longer term development and deployment of a range of new technologies. All transport modes will need to reduce their emissions significantly compared to the baseline trends, in every region of the world. Although some technologies and measures appear to be available at low or even negative cost, strong policies will be needed to ensure rapid uptake and full use of these technologies and to encourage sensible changes in travel patterns. It must involve industry, governments, and consumers. In many cases the rate of change that will be needed for the market penetration of new technologies and vehicle types is much faster than has occurred in recent

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decades. Large and risky investments will be needed from industry and for the purchases of new types of vehicles by consumers. The challenge to reach the targets described here should not be underestimated.

The Baseline Scenario

Based on recent and expected future trends, in particular population and gross domestic product (GDP) per capita, it is possible to construct a business as usual scenario that suggests a possible future, if there are not strong deviations from the current path. The IEA *World Energy Outlook 2008* provides a reference case scenario that assumes no new policies are implemented and that growth in activity and energy use follows growth in population and GDP roughly as it has in the past, though certain saturation points may be reached, for example, car ownership in wealthy countries (IEA 2008b). The IEA *Energy Technology Perspectives 2008* extends this to 2050 in a baseline scenario (IEA 2008a). For transport, this results in more than a doubling in global transport activity measured by passenger kilometers of travel and a near doubling of energy use. Average transport energy intensity improves somewhat over time, but not nearly enough to offset travel growth and prevent energy use from growing.

For this analysis, a second business-as-usual case was developed that assumes higher growth rates in travel, car ownership, and related indicators. This scenario results in a 130 percent increase in transport energy use by 2050. These and other projections are shown in Figure 2-1. In the baseline and high baseline cases, the mix of fuels remains fairly constant, with petroleum fuels dominant. In the high baseline case, after 2030, biofuels and synthetic gasoline and diesel produced from natural gas and coal grow rapidly as they become competitive with petroleum as oil supplies dwindle.

Figure 2-1: Energy use scenarios

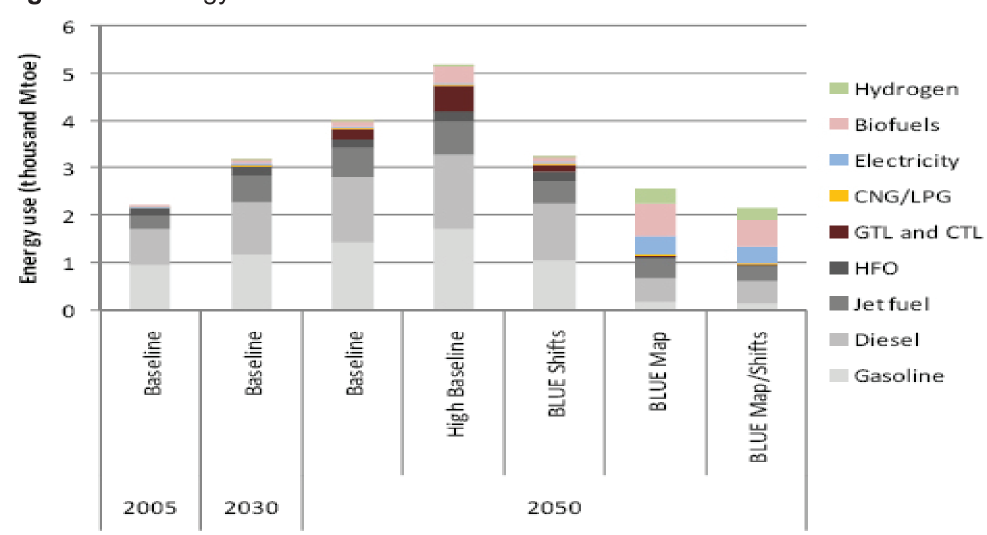
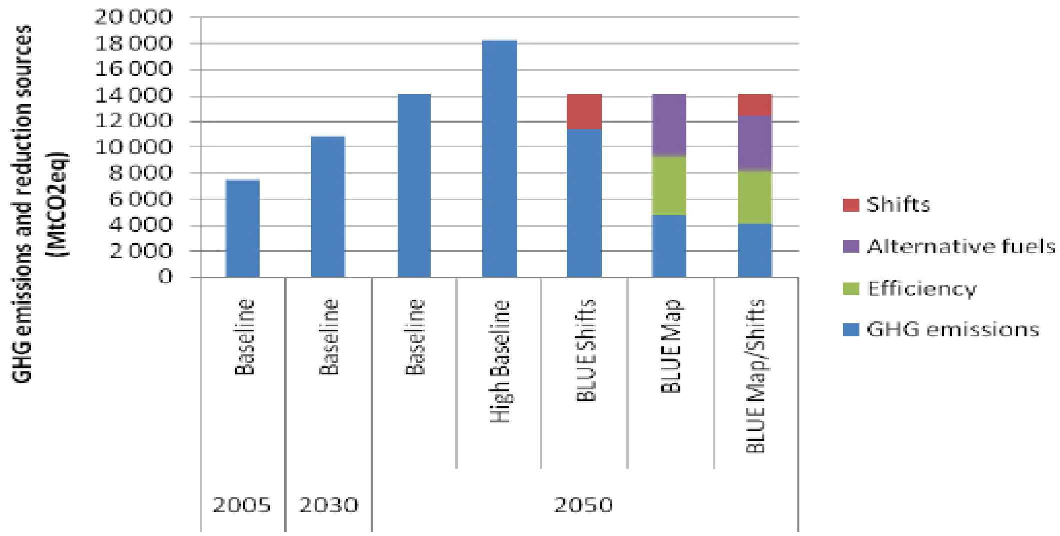


Figure 2-2 shows the CO_2 implications of the baseline and high baseline scenarios. Like energy use, $CO_{2\text{-eq}}$ emissions nearly double in the baseline scenario from 7.5 gigatonnes (Gt) in 2005 to 14 GT in 2050 and grow by about 140 percent in the high baseline scenario to about 18 Gt in 2050. In this figure, and throughout this paper except where noted, GHG emissions include CO_2 emissions from vehicles, and CO_2, methane, and nitrogen oxide emissions from fuel production. It does not include other GHGs, such as water from aircraft or sulfur oxides from shipping.

The scenarios shown in Figure 2-2 are clearly unsustainable from both an energy and CO_2 point of view. The remainder of this paper focuses on alternative, low CO_2 scenarios and how these can be achieved.

Figure 2-2: Summary of GHG reductions by scenario



Recent Transport Trends Around the World

The growth in energy use and CO_2 emissions in the baseline and high baseline cases is driven by expected increases in travel that are mostly a function of increasing car ownership and air travel, both in turn driven by rising incomes around the world. While travel data are still scarce for many countries, the IEA has collected enough data to be able to make some initial estimates of total travel worldwide and by region that provide at least order-of-magnitude estimates of where things stand and where they may be headed.

Figure 2-3 shows estimated passenger travel by mode for regions including and excluding nations belonging to the Organization for Economic Cooperation and Development (OECD and non-OECD, respectively) in 2005, and projected in the baseline scenario to 2050. It shows that total passenger travel in non-OECD countries is expected to soar between 2005 and 2050 and to far surpass travel within the OECD region by 2050.

Figure 2-3: Passenger travel by region and mode, 2005 and 2050

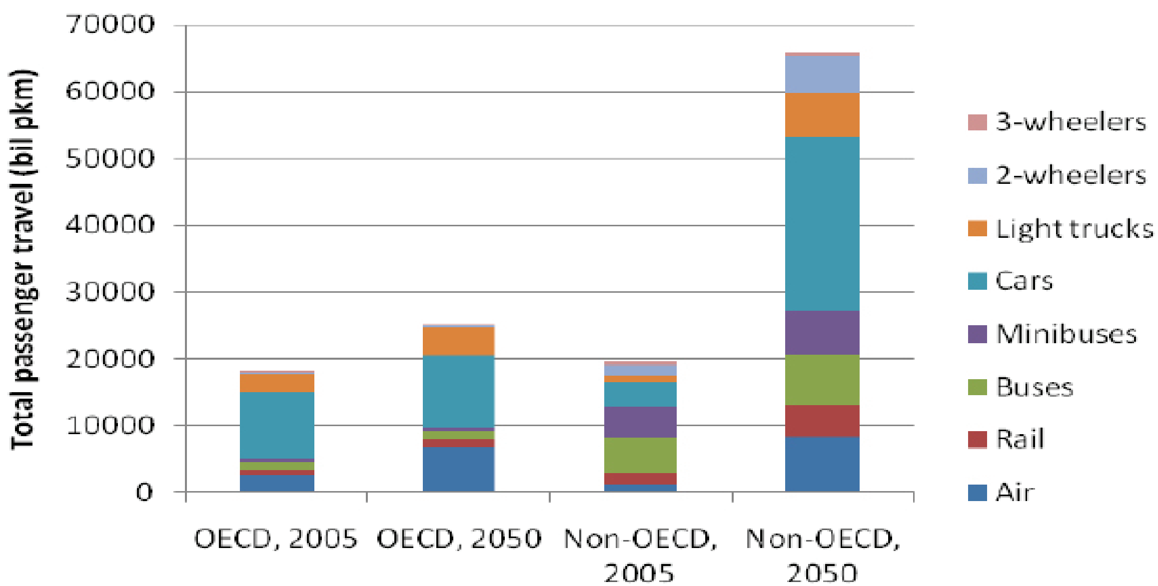
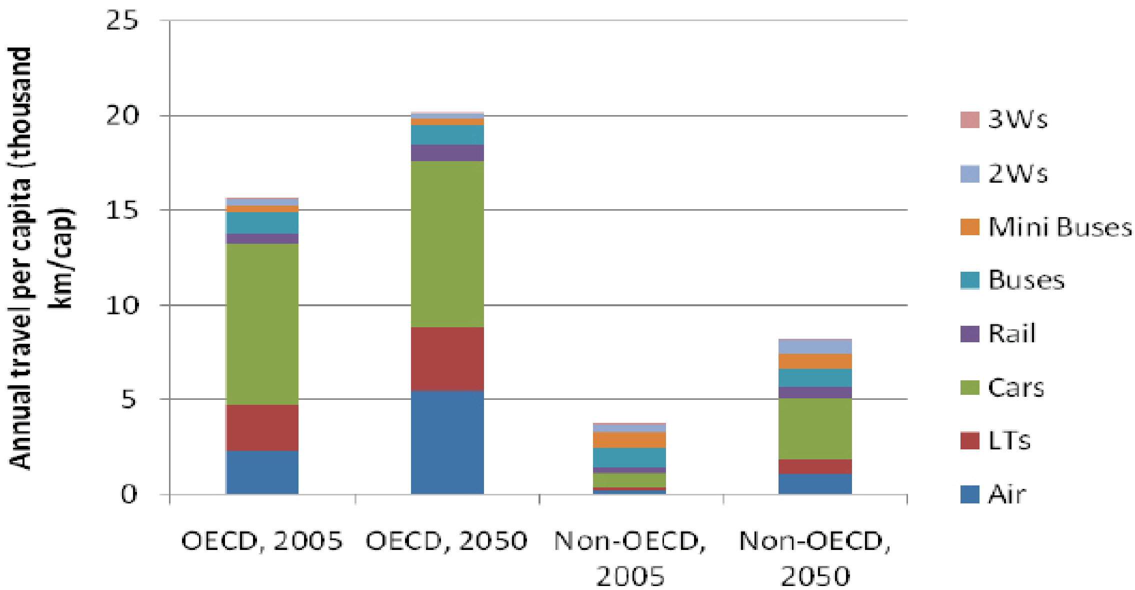


Figure 2-4 shows the same data on a per capita basis. The data show that levels of travel per capita in the developing world are currently far below those in OECD countries, and that travel will grow faster in the developing world than within OECD nations. This is not surprising since population and incomes are expected to grow faster in the developing world, and travel starts from a much smaller base so there is significant potential for a latent demand for travel. However, travel levels per capita in 2050 in non-OECD regions remain well below those in OECD regions, suggesting that even then, travel will not have equalized around the world. Growth may continue to grow rapidly in developing countries for many more decades.

Figure 2-4: Passenger travel per capita by region and mode, 2005 and 2050



In addition, in all regions the growth in travel in the baseline scenario is expected to be mostly by light duty vehicles (LDVs) and air. Rail and bus travel levels are not expected to growth substantially, and as a result, will lose market share fairly dramatically.

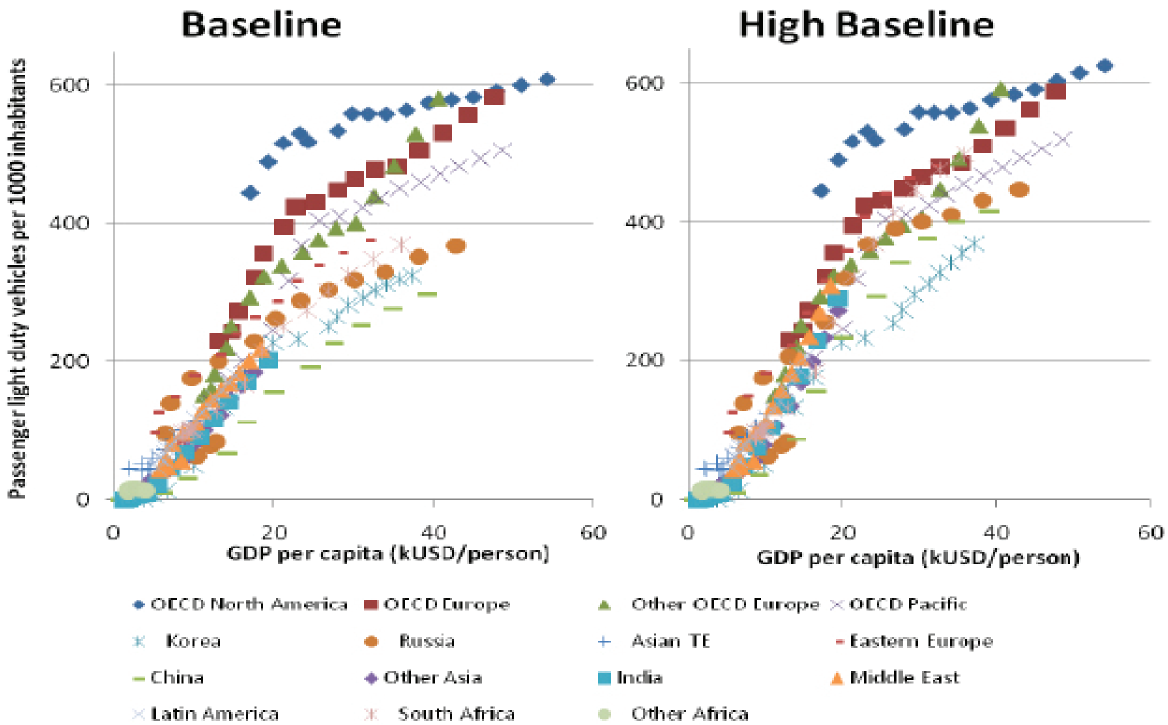
A central driver for the changes in passenger travel in the future is expected to be growth in car ownership. Figure 2-5 shows the IEA projections of car ownership as a function of income growth in countries and regions around the world, through 2050, based on income growth projections and car ownership data in each region. In the baseline scenario, car ownership in most developing countries is assumed to be at a relatively low level for a given income in the future, following the examples of countries like Japan and, especially, South Korea over the past two to three decades. In the high baseline scenario, countries are assumed to have car ownership levels that are closer to European country levels at a given income. The difference in the results for these two types of assumptions is dramatic. In the baseline scenario, car ownership reaches about 2.1 billion passenger LDVs by 2050, compared to about 800 million in 2005. In the high baseline, car ownership approaches 3 billion cars.

The BLUE Map Scenario: A Sustainable Pathway for Transport

In order to change the directions, it will be necessary to radically alter transport activity trends. The IEA has explored several scenarios of low CO_2 futures and their implications for how transport must change and what can help bring about the needed changes.

The BLUE Map scenario is the low-CO_2 scenario developed by the IEA. It forecasts a 70 percent reduction in CO_2 emissions in 2050 compared to the baseline scenario and a 30 percent decrease compared to

Figure 2-5: Car ownership growth in the baseline and high baseline cases



2005 levels. This dramatic reduction can be achieved through the uptake of technologies and alternative fuels across all transport modes that cost up to $200 (U.S. dollars) per metric ton of CO_2 saved. Under this scenario, improvements in transport energy efficiency offer the largest and least expensive 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 energy use reductions in 2050 are shown above in Figure 2-1 in terms of CO_2 in Figure 2-2.

Vehicle Efficiency Improvements

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_2 emissions per kilometer of new LDVs 30 percent by 2020 and 50 percent by 2030 worldwide. 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 stock average improvements of 20 to 25 percent by 2050. The 30 to 50 percent reduction in fuel use per kilometer traveled for trucks, ships, and aircraft by 2050 appears possible, however. For all modes and types of vehicles, the identification and setting of efficiency targets for the 2020 to 2030 time frame would be valuable to help stimulate and coordinate action, particularly if backed by the development of policies around the world to help achieve these targets.

A 30 to 50 percent 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_2 enough to stabilize it at 2005 levels. To go well below 2005 levels, switching to new low-CO_2 fuels and reducing growth in vehicle use will need to play increasingly important roles.

Alternative Fuels

In the baseline scenario, petroleum-based fuels continue to provide over 90 percent of all transport fuel in 2050, while in the high baseline, an increasing share of very high CO_2 fuels, such as coal-to-liquids, contribute to rapidly increasing CO_2 emissions. By contrast, the share of petroleum and other fossil fuel use falls to below 50 percent in the BLUE Map scenario. They are replaced by a combination of advanced, low CO_2 biofuels, electricity, and hydrogen. Any one of these options has the potential to be sufficient to achieve the targets set in the BLUE Map scenario, but each also has drawbacks and may not reach its full potential. A combination can maximize 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 wise to maximize the potential benefits, while limiting costs.

Ethanol from sugar cane can already provide low cost biofuels today, and increasingly does. Advanced second generation biofuels such as lignocellulosic ethanol and biodiesel derived from biomass appear to have the best long-term potential to provide sustainable, low lifecycle GHG fuels, but more research, development, and demonstration 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, water supply, and sensitive ecosystems as a result of land use changes. 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 biomass waste strams where possible and only a small share of global agricultural land.

Advanced Vehicle Technologies

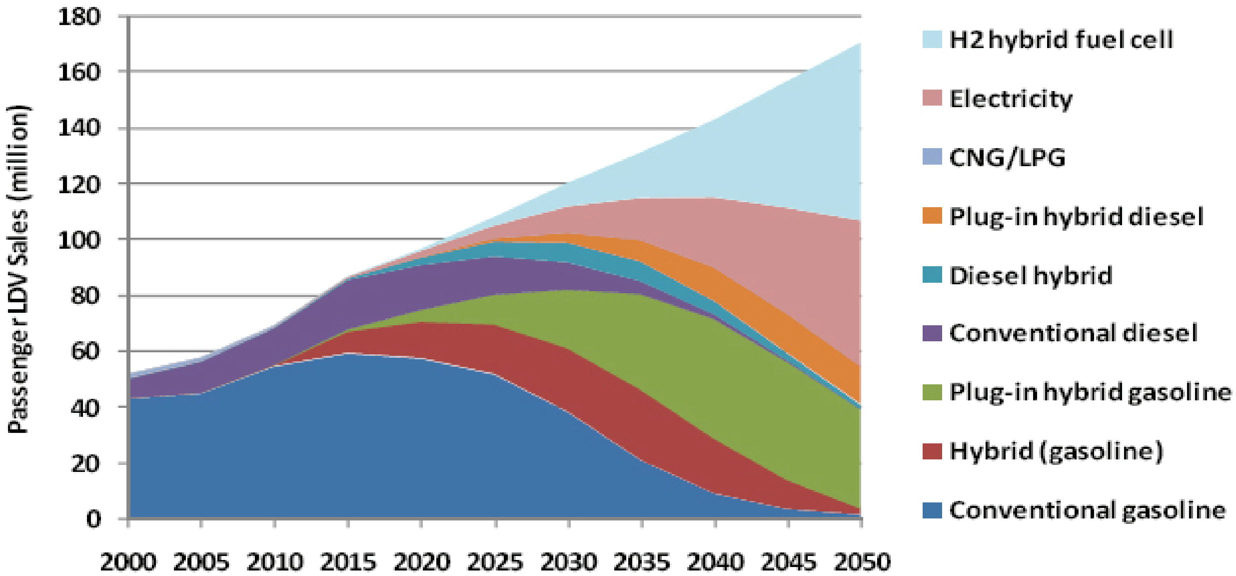
Battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FCVs) play an important role in the BLUE map scenario, especially after 2020. BEVs are rapidly emerging as an important option, especially as lithium ion battery costs decline. It now appears that batteries in high-volume production might cost as little as $500 per kilowatt hour (kWh) in the near term. This is low enough to bring the battery cost for a BEV with a 150 kilometer (km) driving range down to about $15,000. This is still very expensive, but with savings from removing the internal combustion engine, relatively low-cost electricity as the fuel, and government incentives, this cost might be low enough to allow BEVs to achieve commercial success over the next five to ten years. Additional policy assistance, such as support for the development of an appropriate recharging infrastructure, will still be needed, however. The cost of oil, the principal competing fuel with electricity, will also be an important factor.

Since the impact of BEVs on CO_2 emissions depends on the CO_2 intensity of electricity generation, it would make sense to deploy BEVs first in those regions with already low CO_2 generation or a firm commitment to move in that direction. This would include Japan, the European Union, California, and parts of North and South America.

A potentially important transition step to BEVs is represented by PHEVs. By increasing the battery storage in HEVs 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 HEVs, PHEVs use both engine and motor, which adds cost. 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 $5,000 to $6,000 in the near term and provide 40 km of driving range on electricity. For many drivers, this could cut oil use by 50 percent or more. PHEVs also require less new infrastructure than pure BEVs, since the car is not dependent solely on electricity and has a full driving range on liquid fuel.

As shown in Figure 2-6, both BEVs and PHEVs are initially deployed in 2010 in the BLUE Map scenario and increase in sales to well over one million vehicles per year by 2020. BEVs 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 in a small share of trucks. The widespread introduction of BEVs illustrated in the BLUE Map scenario requires adequate investments and coordination among governments and industry for the development of recharging infrastructure. In a separate scenario called BLUE EV Success, in which BEVs almost fully dominate LDV sales by 2050, their sales exceed 100 million vehicles per year.

Figure 2-6: LDV sales and sales shares by vehicle type in BLUE map



Hydrogen FCVs also play a key role in the BLUE Map scenario. FCVs share the market with BEVs and are produced commercially beginning around 2020. They reach a significant sales share by 2030. Sales then rise rapidly to nearly 60 million vehicles by 2050. Recent cost reductions in fuel cell systems for vehicles increase the likelihood that FCVs can eventually become commercialized, although costs and onboard energy storage are still important concerns. As battery costs drop, hybridizing fuel cells appears increasingly attractive, since batteries can help provide peak power to the motor, thereby allowing a smaller fuel cell stack to be used and improving efficiency through regenerative braking. The development of a hydrogen production and distribution infrastructure is necessary and will require substantial new investments. Like electricity, hydrogen must be produced with low CO_2 technologies in order for FCVs to provide significant CO_2 reductions. This will result in higher hydrogen costs than if produced from fossil fuels, for example, by reforming natural gas.

Figure 2-7: CO_2 intensity of different modes by year and scenario

Vehicle efficiency improvements and the shift to lower carbon fuels results in a dramatic decarbonization of all types of transportation by 2050. Figure 2-7 shows that the average CO_2 intensity of different modes will drop dramatically by 2050 in the BLUE Map scenario, reaching well below 50 grams of $CO_{2\text{-eq}}$ emissions per km of driving for all modes except air travel. This means that modal shift would provide less CO_2 benefit than it does currently. Since there is no guarantee that such CO_2 intensity reductions will be achieved, however, modal shift options make sense as a complement to vehicle and fuel options to reduce CO_2.

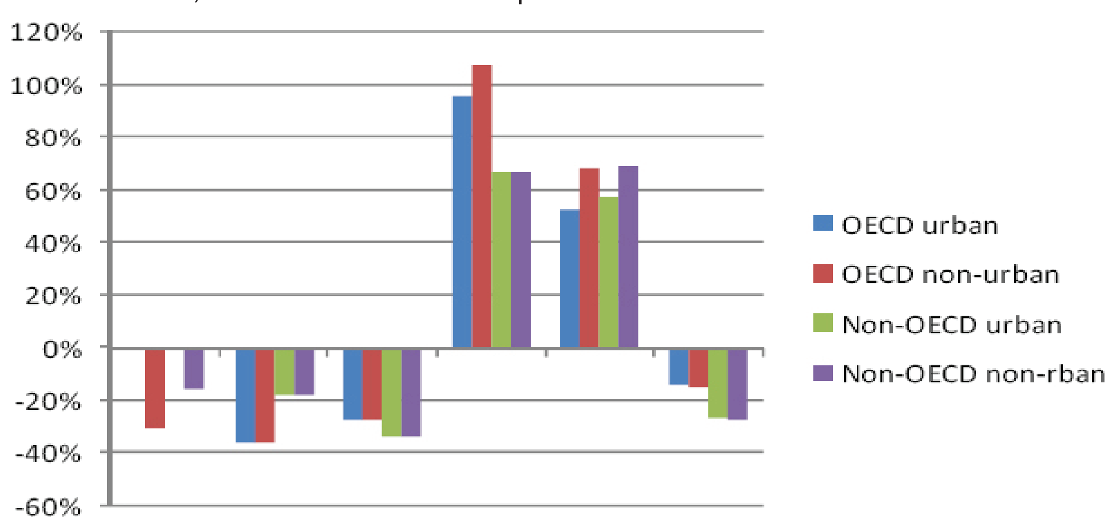
The BLUE Shifts Scenario

Certainly in cities around the world, development that minimizes the need for private motorized travel should be a high priority given the strong cobenefits in terms of reduced traffic congestion, pollutant emissions, and general liveability.

The BLUE Shifts scenario considers one possible future modal mix, in contrast to the one implied in the baseline scenario. This scenario relies on more uncertain information compared to other projections. It has been developed by the IEA to provide a basis for estimating the important potential energy and CO_2 impacts of modal shifts.

As shown in Figure 2-8, the BLUE Shifts scenario envisages an average worldwide reduction in private LDV and aviation passenger travel of 25 percent by 2050 relative to the baseline scenario, and up to a 50 percent reduction compared to the high baseline scenario. In addition, it includes a shift in freight movement to rail transport that reduces long-haul truck transport growth between 2010 and 2050 by half. Shifting travel and goods transport to advanced bus and rail systems, with some outright reductions in travel growth due to better land use planning, improved non-motorized transport infrastructure, and some telecommunications substitution for travel, could yield a 20 percent reduction in energy use by 2050 compared to the baseline, or a 40 percent reduction compared to the high baseline scenario. Even more ambitious mode shifting may be possible, but this will require strong policies and political will.

Figure 2-8: Percentage changes in passenger travel by mode, region, and urban/non-urban, BLUE Shifts scenario compared to baseline in 2050

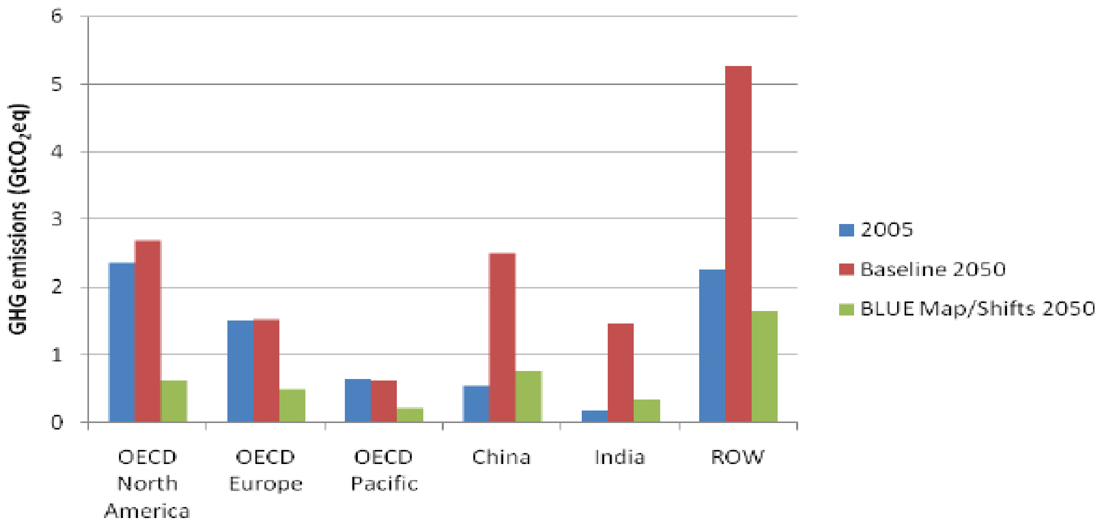


The BLUE Map/Shifts Scenario

When the impacts of improved efficiency, low carbon fuels, and advanced vehicles and modal shift are combined in the BLUE Map/Shifts scenario, CO_2 emissions in transport are cut by 40 percent in 2050 compared to 2005, and by 70 percent compared to the baseline scenario in 2050, as shown earlier in Figure 2-2. This represents a 10 Gt reduction from the 14 Gt that would otherwise be emitted by the transport system in 2050 in the baseline scenario and a 14 Gt reduction compared to the 18 Gt in the high baseline scenario. After 2050, further modal shifting and efficiency improvements, and the deeper penetration of low CO_2 alternative fuels, will be needed to keep transport on a downward CO_2 trend.

As shown in Figure 2-9, the change in CO_2 varies considerably by region, with OECD regions experiencing deep reductions compared to 2005 levels, and most non-OECD regions staying near or slightly above 2005 levels, although far lower than their CO_2 growth in the baseline scenario. All world regions must deeply decarbonize transport by 2050 compared to baseline scenario trends if the overall targets are to be achieved.

Figure 2-9: Transport CO_2 emissions by region, year, and scenario



Modal Findings and Policy Considerations

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.

The four most important modes, in terms of their expected contribution to CO_2 in the baseline scenario in 2050, are LDVs, which account for 43 percent of the reductions, trucks with 21 percent, aviation with 20 percent, and shipping with 8 percent. In the BLUE Map/Shifts scenario, the role for buses and rail increases significantly and CO_2 reductions from efficiency improvements and alternative fuel use in these modes become increasingly important, though they are already quite efficient.

Light Duty Vehicles

Passenger LDV ownership around the world is expected to rise mainly as a function of income. In the baseline scenario, the total LDV stock increases from about 700 million in 2005 to nearly two billion by 2050. 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, and long-distance bus and rail systems could also help reduce fuel use by encouraging people to use alternatives to cars more often.

Based on IEA analysis and various other recent studies (e.g. Cheah *et al* 2007), it seems possible, and is likely to be cost effective even at relatively low oil prices, to achieve a 50 percent reduction in fuel use per kilometer for new LDVs around the world by 2030, relative to 2005 levels, from incremental technology improvements and electric hybridization. Net negative CO_2 reduction costs are achievable at least for much of this improvement, but it will be important to ensure that the efficiency gains are not simply offset by trends toward larger, heavier, and faster cars. Policies will be needed to ensure that maximum uptake of efficiency technologies occurs and that the benefits are translated into fuel economy improvement. Fuel economy standards, perhaps complemented by CO_2-based vehicle registration fees, can play an important role in OECD countries. It is important that non-OECD countries adopt similar policies, and that all countries continue to update these policies in the future, rather than letting policies expire. The Global Fuel Economy Initiative (GFEI 2009) is focused on helping achieve such outcomes.

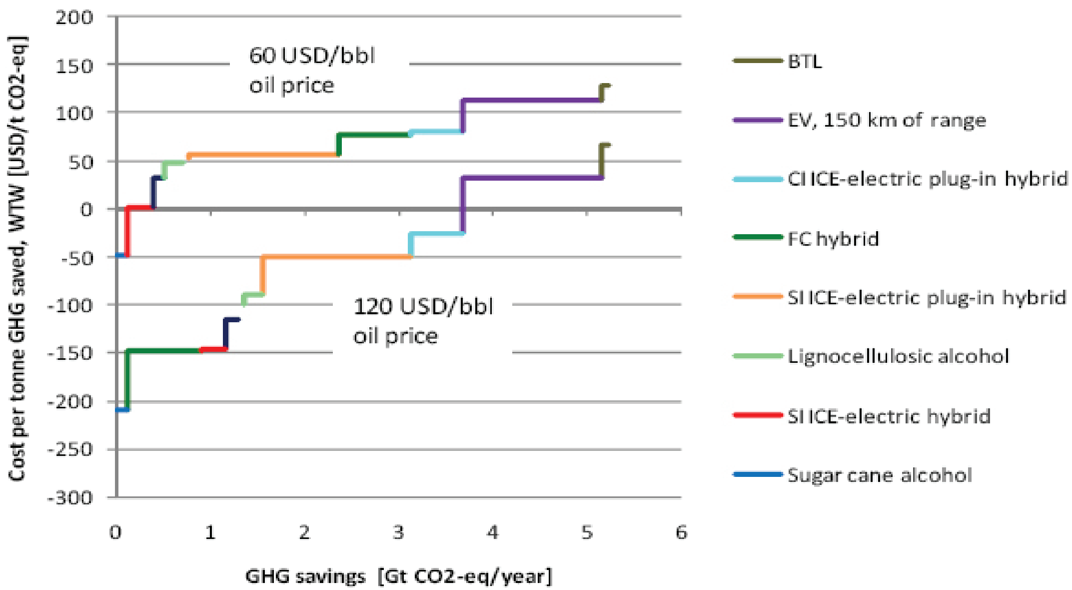
Advanced technology vehicles will need to play an increasingly important role, especially after 2020. Initiatives to promote BEVs and PHEVs, and the continuing development of FCVs, will be important. The BLUE Map scenario includes annual sales of over five million PHEVs and two million BEVs by 2020, rising to around 50 million of each type of vehicle by 2050. It also predicts sales of tens of millions of FCVs by 2050. For governments, undertaking ongoing RD&D programs to cut technology costs, orchestrating the co-development of vehicle and battery production, recharging and hydrogen infrastructure, and providing incentives to ensure sufficient consumer demand to support market growth will be important near-term activities. Selecting certain regions or metropolitan areas that are keen to be early adopters of new vehicle types may be an effective approach.

Biofuels for LDVs and other transportation modes could play an important role, but their use may be limited by the availability of sustainable and truly low-CO_2 feedstocks. Second generation biofuels from lignocellulosic and other non-food feedstocks reach about 25 percent of LDV transport fuel by 2050 in the BLUE Map scenario, nearly 20 times 2008 levels worldwide. Fuel compatibility with vehicles is not likely to be a significant problem, needing only minor modifications to new vehicles in the future. A transition is needed to much more sustainable feedstocks and approaches to biofuels production, however. As sustainability criteria and rating systems emerge, policies need to shift toward incentivizing the most sustainable, low-CO_2, and cost-efficient biofuels, while minimizing impacts from land use changes. CO_2 differentiation through the low carbon fuel standard now in effect in California (CARB 2009) represents an important step. A transition to second generation production techniques is particularly needed in OECD countries, since their current biofuels production is dominated by ethanol from grain crops and biodiesel from oil-seed crops. These compete with food and animal feed supplies and are costly in terms of CO_2 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_2, and they often provide other important benefits, including reduced traffic congestion, lower pollutant emissions, and more liveable cities. Policies need to focus on better urban design to cut the need for motorized travel, improving 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 2-10 shows the role and estimated marginal cost of different technologies and fuels in contributing to CO_2 reductions from LDVs in the BLUE Map scenario in 2050, under $60 and $120 per barrel oil price assumptions. These curves are uncertain, and sensitive to small changes in assumptions. Modal shifts and non-LDV modes are not included due to cost uncertainties. Costs for 2050 for technologies and fuels shown in the figure are partly dependent on earlier deployment, which triggers learning and cost reductions. The curves 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_2 reductions.

Figure 2-10: GHG reductions in BLUE Map for light-duty vehicles and fuels: contribution and estimated cost per tonne by vehicle and fuel type in 2050



Notes: 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.

Despite the uncertainties, the results are revealing. By 2050, deep reductions in $CO_{2\text{-eq}}$ GHG emissions from LDVs on the order of 5 Gt appear possible at a marginal cost of about $210 per metric ton with oil at $60 per barrel. A second case, assuming a higher oil price of $120 per barrel, is also shown. At this higher oil price, the emissions reductions are achieved at a marginal cost of about $130 per metric ton. Most of the emissions reduction is achieved at costs far below this. In earlier years, particularly up to 2030, most cost reductions come from incremental improvements to conventional vehicles and hybridization at very low average cost.

Trucks and Freight Movement

Trucking has been one of the fastest growing transport modes over the past few decades. This growth is likely to continue, although possibly with some decoupling from GDP as an increasing share of economic growth comes from information and other non-material sectors. Trucks have also become more efficient. Even so, there remain major opportunities to improve efficiency through technical measures, operational changes such as driver training, and implementation of logistical systems to improve efficiency in the handling and routing of goods.

Better technologies, including improved engines, light-weighting, better aerodynamics, and better tires, can probably make vehicles 30 to 40 percent more efficient by 2030. Many of the improvements appear likely to be cost effective, although significant market failures are evident in terms of truck operators failing to adopt cost-effective technologies. In addition, using a societal cost basis for analysis of options increases cost effectiveness well beyond private cost analysis. Logistic systems to ensure better use of trucks and shifts to larger trucks can provide additional efficiency gains system-wide, and may also be quite cost effective. To maximize the gains, governments will need to work with trucking companies, for example, by supporting driver training programs, and to create incentives or requirements for improved efficiency. Japan's Top Runner efficiency requirements for trucks are the first of their kind in the world (JFS 2009).

For many trucks, shifting to electricity or hydrogen as a main fuel will be difficult due to driving range requirements and energy storage limitations. Thus, the development of second generation biofuels may be the only way to substantially decarbonize trucking fuel. Trucks can be easily adapted to burn biodiesel, especially the very high quality biodiesel that is produced by biomass gasification and liquefaction. In the BLUE Map scenario, trucks achieve a 40 percent reduction in energy intensity per metric ton-km, and shift 30 percent of their remaining fuel demand to advanced biofuels by 2050.

Shifting some freight from truck to rail can be an attractive option to save energy and cut CO_2 emissions, due to the high energy efficiency of rail movement. Many countries move only a small share of goods by rail, but to achieve shifts, very large investments in rail and intermodal systems will be necessary.

Aviation

Air travel is expected to be the fastest growing transport mode in the future. Air passenger kilometers 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. It is expected to grow even faster than income during normal economic cycles. Aviation also benefits from steady efficiency improvements in each generation of aircraft, which is likely to continue.

Given the expected very high rate of growth, aviation energy use and CO_2 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, for example, by encouraging aircraft manufacturers to make bigger gains with each generation of aircraft and by improving air traffic control systems. A wide range of fuel efficiency technologies for aircraft remain unexploited, including aerodynamic improvements, weight reduction, and engine efficiency. The estimated potential for improvement suggests that the average aircraft may be nearly twice as efficient in 2050 as it is today.

Table 2.1: Fuel savings and costs from new generation planes

Parameter	*B767*	*B787*	*B747-400*	*B747-800*
Seat Capacity	250	250	460	467
Load factor	80	80	80	80
Energy intensity (MJ/seat-km)	1.9	1.3	1.8	1.4
Fuel use L per plane km	10.8	7.4	18.6	14.7
Annual plane-kilometres of travel per year (million)	2	2	2	2
Annual fuel consumption (million l)	22	15	38	30
Annual savings (million USD, @ USD 120/bbl or about USD 0.90/L)	6.4		8.6	
Savings over 30 years, 10% discount rate, USD millions	60		81	
Savings over 30 years, 3% discount rate, USD millions	125		169	
Approximate aircraft purchase costs (USD millions)	150	190	230	280
Purchase Cost Difference (USD millions)	40		50	

Sources: IEA estimates based on aircraft data from Boeing's website (Boeing 2009) and previous reports. Airplane cost data from Air Guide Online, 2009

Improved air traffic control can also improve the overall fuel efficiency of aviation by between 5 and 10 percent. More work is needed to better understand the cost effectiveness of various options, although available estimates suggest that some available options may be quite attractive. One significant factor in assessing technology cost/benefit for aircraft is that aircraft burn large quantities of fuel over their lifetimes. Up to one billion liters of jet fuel can be burned in a large airplane over its lifetime. Cutting fuel use can provide enormous fuel cost savings. Thus, major investments to improve aircraft efficiency may be cost effective.

The fuel savings associated with two recent aircraft replacements are shown in Table 2-1. A host of new upgrades and features may justify much of the higher cost. Even so, fuel savings alone over 30 years, assuming a 10 percent discount rate and fuel costs of $ 0.90 per liter, fully offset the higher plane cost. Using a 3 percent societal discount rate, fuel savings are far greater than the higher plane cost. This also reveals the fact that, over the 30-year minimum equipment life for aircraft, using a 3 percent discount rate instead of a 10 percent rate doubles the value of fuel savings, in turn indicating that far greater investments in aircraft efficiency are justifiable from a societal point of view than a private or corporate point of view.

Measures such as CO_2 taxes to encourage faster introduction of new technologies reflecting very high societal benefits on successive generations of aircraft can help. International agreements can place a price on or limit aviation GHG emissions. However, GHG reduction is complicated by the fact that CO_2 is just one of several aircraft emissions that have radiative forcing, or warming, effects. Others include nitrogen oxides, methane, and water vapor. 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 fuels is critical for providing adequate aircraft flying range. Shifting from energy dense liquid fuels to gaseous fuels or electricity appears impractical. Liquefied hydrogen may be a viable option, but its use would require major compromises in other airplane design features. High energy-dense biodiesel fuels, therefore, are of great interest to the airline industry, including aircraft manufacturers, as they may hold the best hope of providing low-CO_2 fuels.

In the BLUE Map scenario, 30 percent of aircraft fuel is second generation biofuel by 2050. The BLUE Map/Shifts scenario predicts a cut in air travel growth by 25 percent, resulting in a tripling by 2050 rather than quadrupling. This will occur naturally if alternatives such as high-speed rail systems are provided, but it must also be encouraged by policies that 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.

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. Transoceanic shipping now represents about 90 percent of all shipping energy use. The remainder is river and coastal shipping. Container shipping fuel use has risen faster than any other ship category, and it may continue to rise rapidly in the future. The average size of ships is also rising, such that shipping is becoming steadily more efficient per metric ton-km moved.

Ship efficiency has not been improving significantly in recent years. The structure of the shipping industry, with fragmented and very different systems of ownership, operation, and registration, often involving several different countries for a single ship, may serve to limit the market incentives to optimize ship efficiency.

The IEA has identified about 50 efficiency improvement measures for shipping (IEA 2009). If most were adopted, a 50 percent or greater reduction in energy use per metric ton-km could be achieved. More economic research is needed, but recent studies suggest that many options for retrofitting existing ships could achieve substantial energy and CO_2 savings at very low or net negative cost.

As for aircraft, biofuels are likely to be important for the decarbonization 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 percent of shipping fuel is low GHG biofuel by 2050.

Policies to promote improved international shipping efficiency and CO_2 reduction may have to come from international agreements. Shipping could be included in a CO_2 cap-and-trade system. Another proposal has been to develop a ship efficiency index and 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 for existing ships are available. More work is needed to develop such an index, and in particular to estimate the efficiency benefits and costs for various types of improvements. The UN International Maritime Organisation is playing a lead role in such efforts.

Conclusions

It appears that, by 2050, it should be possible to cut transport energy use and CO_2 emissions nearly in half compared to baseline projections through efficiency improvements, and by nearly half again by substitution of very low-CO_2 alternative fuels, mainly electricity, hydrogen, and biofuels. Modal shifting can also help, particularly in the 2010 to 2030 time frame, before private modes, such as LDVs, have become significantly decarbonized.

While CO_2 reduction costs are uncertain, the efficiency improvements should be, on average, cost effective, with an average cost per metric ton for LDVs near zero using a societal discount rate. The costs of many options available for trucks, ships, and aircraft appear near zero on a cost per metric ton basis, but costs are uncertain at the margin. The biggest uncertainty, however, is the cost for producing large numbers of BEVs or FCVs. If targeted cost reductions are achieved, these technologies should provide CO_2 reductions by 2050 at net costs below $200 per metric ton, and perhaps below $100 per metric ton. However, in a more pessimistic scenario, with fewer cost reductions, the costs of these technologies may well exceed $200 per metric ton.

International cooperation to move things in the right direction will be critical. A significant reduction in CO_2 emissions in transport will be possible only if all world regions contribute. Although transport emissions per capita are far higher today in OECD than in non-OECD countries, nearly 90 percent of all the future CO_2 growth is expected to come from non-OECD countries. In the IEA BLUE scenarios, all regions cut transport CO_2 dramatically compared to the baseline in 2050. Vehicles can be made more efficient in all regions of the world, generating large fuel savings worldwide. Changes in travel can also occur, although in many countries the main priority is to preserve current low-energy travel modes. Alternative fuels, if their costs can eventually approach those for oil-based fuels, will also contribute to CO_2 reductions worldwide.

Governments 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 maximize efficiency and limit the cost of future changes. Common medium- and long-term targets in terms of fuel economy, alternative fuels use, and modal shares would send clear signals to key players and help them plan for the future. For those producing efficient products, knowing that a wide range of markets will be eager for those products will help plan production and, eventually, to cut costs. The Global Fuel Economy Initiative represents an important example of moving toward greater international co-operation in developing targets and standards.

National governments need to develop and deploy new types of very low GHG vehicles and fuels. Technologies such as BEVs and FCVs can only be introduced into markets where there is adequate refueling infrastructure, and consumers willing and ready to purchase both the vehicles and the fuels. Markets alone will have difficulty achieving such outcomes. Governments around the world must orchestrate such transitions and help overcome the risks involved.

To put transport on a sustainable pathway over the coming 40 years, current trends must be changed substantially within the next five to ten years. Strong policies are needed to begin to shift long-term trajectories and to meet interim targets. Strong measures are also needed in terms of investments in infrastructure and incentives that can influence how people choose to travel.

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