DRAFT

Opportunities for Greenhouse Gas Mitigation in Transport and Implications for Investment

David L. Greene

July 28, 2007

I. Introduction

At COP 12, Parties agreed on important mandates requesting the secretariat to undertake work on existing and planned investment flows and finance schemes relevant to the development of an effective and appropriate international response to climate change. These mandates imply a particular focus on developing countries' needs, including their medium- to long-term requirements for investments and finance.

This strategy is especially important for the transportation sector. Motorization of transport and automobile ownership rates are increasing rapidly in developing countries experiencing strong economic growth. Vehicle travel continues to grow steadily in developed and developing economies, and economic globalization is driving increases in international shipping and air transport. Investments made over the next two decades in transport infrastructure, advanced energy efficient technology, biofuels and research, development and demonstration will have major impacts on transportation's greenhouse gas emissions through 2030, and beyond.

Transport, as defined in this report includes passenger and freight movements by road vehicles, railways, aircraft, and both inland and maritime vessels. For aircraft and marine transport, both domestic and international energy use and emissions are included. Investment needs for greenhouse mitigation are estimated to 2030 via comparison of two IEA World Energy Outlook 2006 (WEO) scenarios: 1) Reference or Business as Usual (BAU) and 2) Mitigation or Beyond Advanced Policy Scenario (BAPS). Four different methods are used to estimate the investment costs needed to achieve the additional carbon dioxide reductions of the BAPS scenario. The first method allocates total transport mitigation costs as estimated by the IEA to countries and regions in proportion to their estimated total transport or motor vehicle investment requirements. The second method estimates the combined costs of mitigation across the entire transport sector, excluding investments for biofuels production, using a mitigation cost curve derived by Vattenfall (2007). The third method estimates the costs of advanced light-duty vehicle technologies, including hybrid vehicles and flex-fuel ethanol vehicles, using technology-specific cost estimates published in IEA (2006b). These estimates can be subtracted from the mitigation cost curve estimates to obtain estimated mitigation costs for heavy duty vehicles and non-road modes. Finally, investment costs for increased production of biofuels are estimated using capital cost estimates from IEA (2004) and Vattenfall (2007). These investment costs are in addition to those estimated by the previous two methods.

The current situation with respect to energy consumption and greenhouse gas (GHG) emissions is reviewed first, followed by a discussion of significant trends. Next, current financing sources are reviewed, including debt, equity, grants and other sources. The next two sections examine and compare business as usual and aggressive mitigation scenarios, and derive estimates of additional investments required to achieve the BAPS Mitigation Scenario. The analysis relies on the energy projections and energy-related investment analyses of the International Energy Agency's *World Energy Outlook 2006* (IEA, 2006). An assessment is made of the ability of current sources of investment to meet the needs of the mitigation scenario, and changes that may be needed are proposed.

II. Current Situation

Transport emits about 14% of global greenhouse gases, 5.4 Gigatons (Gt) carbon dioxide (CO_2) equivalent in 2002 nearly all of which is carbon dioxide (Vattenfall, 2007). Transport accounts for one-fifth of energy-related CO_2 emissions: 5.3 Gt in 2004 (IEA, 2006) (Figure 1). From the previous two numbers it can be inferred that carbon dioxide accounts for approximately 98% of the global warming potential (GWP) of transport's greenhouse gas emissions. Vattenfall (2007) estimates 97%, but the IEA's (2006) estimate of 95% for 2003 is probably more accurate. However, sources disagree on this point. The Fourth Assessment Report, for example, reports that 8.9% of U.S. transport emissions' GWP is due to the combined effect of Fluorinated(F)-gases, 2.0% is due to nitrous oxide, and 0.2% to methane. This report will focus on transport's energy-related carbon dioxide emissions although the sources considered give some consideration given to N_2O and F-gases from mobile air conditioning. Non-CO_2 GHG emissions from transport, especially those from aircraft, are relatively less well understood and could be of increasing concern (IPCC, 2007, Ch.5, Box 5-1).

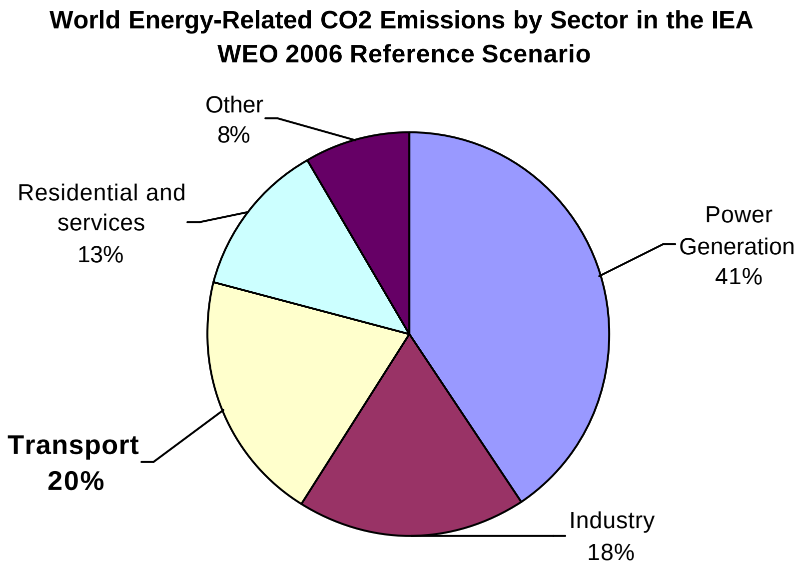


Figure 1. World Energy-Related CO_2 Emissions by Sector in the BAU Scenario

Regionally, North America is the largest source of transport emissions, accounting for almost 40% of the world total in 2002 (Vattenfall, 2007).

Road transport, including passenger and freight, is responsible for almost three fourths (73%) of the sector's energy use and CO_2 emissions (Figure 2). Air is in distant second with 12%, followed by marine (10%), rail (4%), and all other modes (1%) (Vattenfall, 2007). The volume and distribution of road transport by mode varies widely across regions (Figure 3). In 2000, North America and Western Europe had 50% more vehicle miles of road travel than the rest of the world combined. This situation is changing rapidly as vehicle ownership increases in the developing and transitional economies. Two and three-wheel motor vehicles are a significant share of road traffic in Eastern Europe, Latin America, Japan and South and Southeast Asia. Light trucks are a large share of road traffic in the Americas.

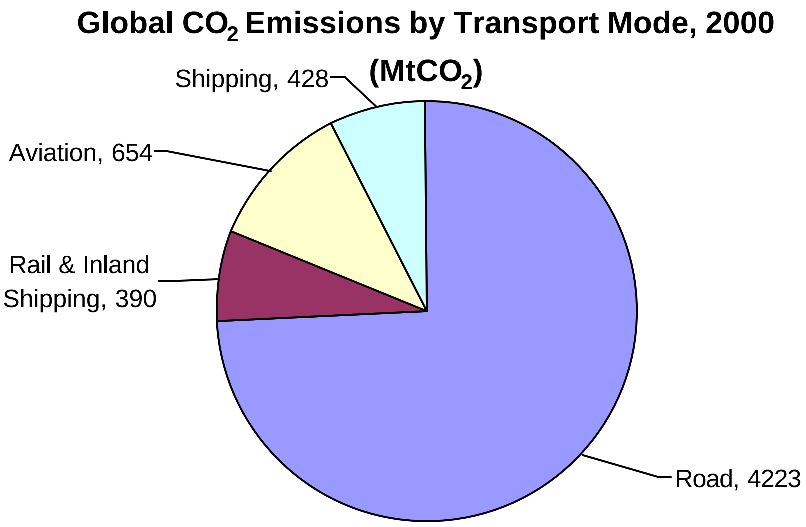
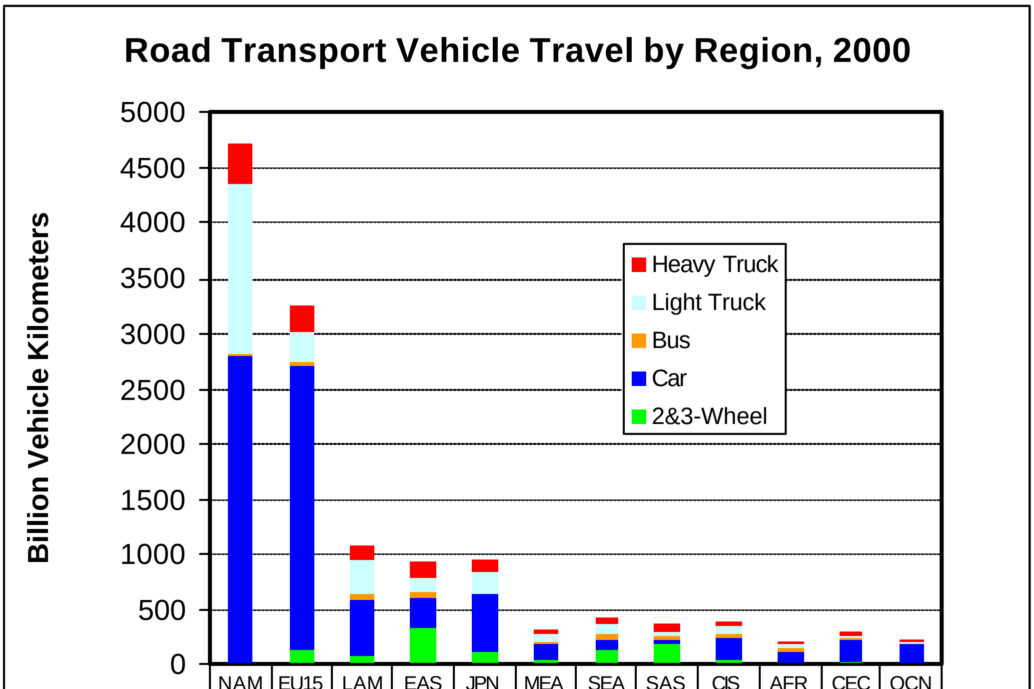


Figure 2. Global CO2 Emissions by Transport Mode, 2000 (Borken, et al., 2007)



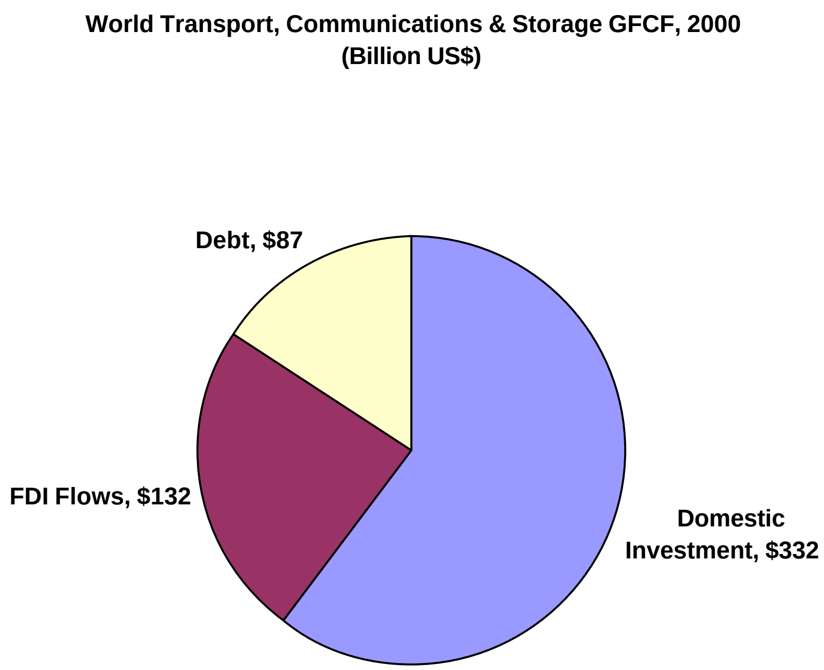
	NAM	EU15	LAM	EAS	JPN	MEA	SEA	SAS	CIS	AFR	CEC	OCN
Heavy Truck	390	234	119	154	115	23	56	74	44	25	35	14
Light Truck	1518	268	318	135	185	76	98	37	68	49	24	32
Bus	32	28	50	40	7	15	43	30	32	27	14	3
Car	2769	2574	511	291	524	146	96	50	188	104	193	171
2&3-Wheel	18	139	80	321	112	44	138	186	55	16	31	3

Figure 3. Road Transport Vehicle Travel by Region, 2000 (Borken et al., 2007).

Petroleum dominates energy use by transport. In 2004, world transport consumed 1,969 million tonnes of oil equivalent energy, of which 1,861 (94.5%) was petroleum. Biofuels accounted for only 15 Mtoe (0.8%), and all other energy sources (mostly electricity and natural gas) accounted for 93 Mtoe (4.7%) (IEA, 2006).

Investments in transportation vehicles and fuels are made almost entirely by the private sector. Consumers and businesses purchase vehicles and fuels for their own use, vehicle manufacturers and energy companies use the revenues from sales to finance their investments in research, development and productive capacity. Nationally owned oil companies are a significant exception, but many of these not only function in a self-financing mode but are major sources of revenue for other government activities. Another important exception in the transport sector are mass transit properties which, in some countries are owned and operated by governments and in others receive government subsidies. Road development, ports and airports, and public transport projects in developing economies are the most common mode of international investment in transport.

Figure 4. World Transport, Communications & Storage Gross Fixed Capital Formation, 2000



Investment in transport infrastructure is overwhelmingly government financed for road transport systems airports, and ports, with private sector financing most common for rail and pipeline systems. However, numerous counterexamples can be found.

Of the estimated $551 billion in worldwide gross fixed capital formation (GFCF) in transport in 2000, 60% was domestically financed, 24% was foreign direct investment and 16% debt financed (Figure 4). In the five largest (+5) developing countries (China, India, Mexico, South Africa and Brazil) domestic investment made up 71% of transport GFCF, FDI comprised 27% and debt only 2%. China and India finance almost all transport GFCF domestically. In the least developed economies domestic investment amounted to 80% and FDI 20% of total GFCF in 2000.

Official Development Assistance (ODA) for transport in 2000 went primarily to developing Asia, Latin America and Africa (Figure 5). Developing Asia received 64% of the world total transport ODA of $7.8 billion $US in 2000. The +5 developing economies received $3.1 billion, with China accepting $1.7 billion and India $1.1 billion. Total transport ODA is half bilateral and half multilateral, each contributing $3.9 billion. The $7.8 billion in ODA comprised 20% of the $38.3 billion US of GFCF in developing economies in 2000.

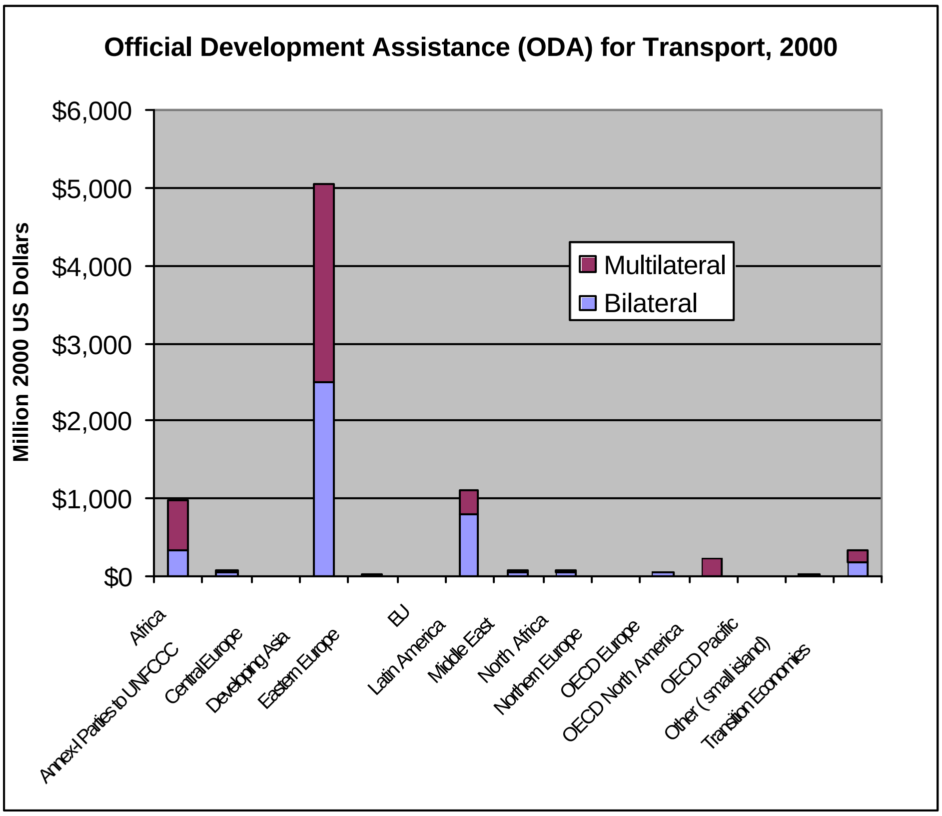


Figure 5. Official Development Assistance for Transport, 2000.

By 2005, bilateral ODA for transport had increased to $5.6 billion and total ODA had grown to $11.4 billion, about 2% of global GFCF in transport. The great majority of the assistance went to road transport projects, followed by rail, policy and management assistance, and air and water (Figure 6).

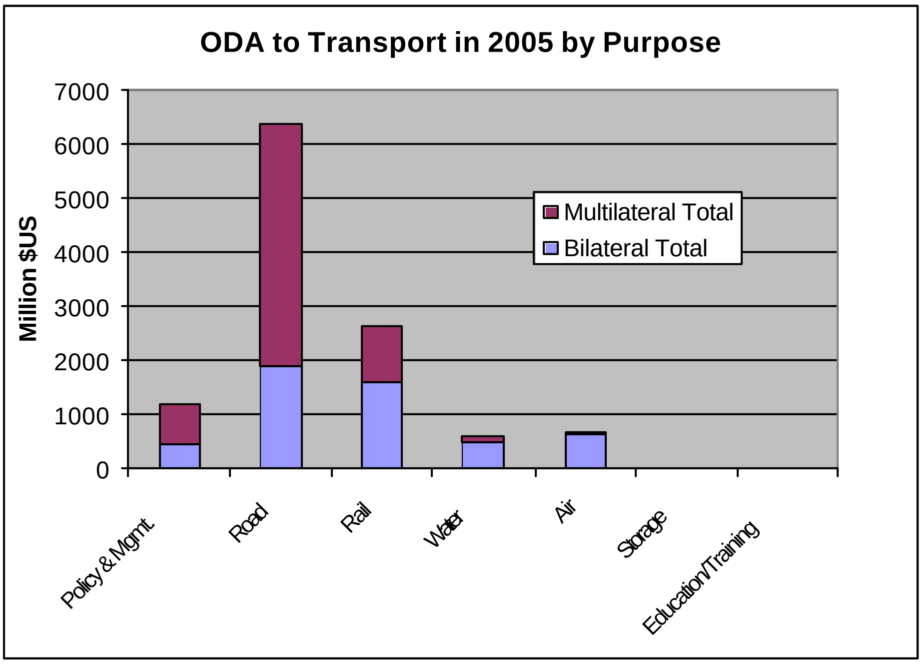


Figure 6. ODA to Transport in 2005 by Purpose.

Few projects of the Global Environmental Fund (GEF) have addressed either energy efficiency or alternative fuels in the transport sector. Through 2006, a total of 16 transport energy efficiency projects had been funded with 6 more in the pipeline, with a total funding level of $147 million US. Over the same period, 6 alternative fuels projects were funded or in the pipeline with a total funding level of $27 million.

III. Reference Scenario

The IEA 2006 World Energy Outlook (IEA, 2006) Reference Scenario assumes moderate population growth (1%/year, on average) and solid GDP growth (3.4%/year). Per capita income grows more rapidly in the transition and developing economies than in the OECD, still per capita income in OECD countries in 2030 is almost four times the average for the rest of the world. Economic growth and rising incomes in the developing world enable a rapid transition to motorized transport driven by rising motor vehicle ownership. Vehicle sales in OECD countries increase by a small amount but sales in the developing economies triple. As a result, from 100 light-duty vehicles per 1,000 persons today, world ownership rates increase to 170 in 2030 in both the Reference and Mitigation Scenarios. New vehicle sales increase from just under 50 million units per year in 2005 to 92 million in 2030. Of that total, approximately 48 million units are sold in the developing economies and only 44 million in the OECD in 2030. As a consequence, most of the increase in world oil demand comes from the developing world. China and the rest of developing Asia account for 15 million barrels per day (mb/d) of the 33 mb/d increase in oil use from 2005 to 2030. Although oil use in the EU and North America increase more slowly, still North America accounts for 5.9 mb/d of the rise in oil use. The price of petroleum is assumed to fall to $47 per barrel by 2012 but then rise gradually to $55 in 2030.

End use technologies in all sectors including transport are assumed to become steadily more energy efficient over time. Second generation biofuels (from cellulose) are not assumed to be available on a large scale by 2030. Hydrogen fuel cell vehicles are assumed to begin to play a very minor role in transport after 2020. The Reference Scenario takes account of government policies and measures enacted or adopted by mid-2006 and possible future policies are not considered.

a. Energy consumption and mix, GHG emissions

In the Reference Scenario (BAU) petroleum remains the dominant source of energy for transportation (Figure 7). Biofuel use increases from 19 to 92 Mtoe, but this still represents only 3% of world transport energy use in 2030. Other energy sources, including electricity and natural gas actually decrease in relative importance.

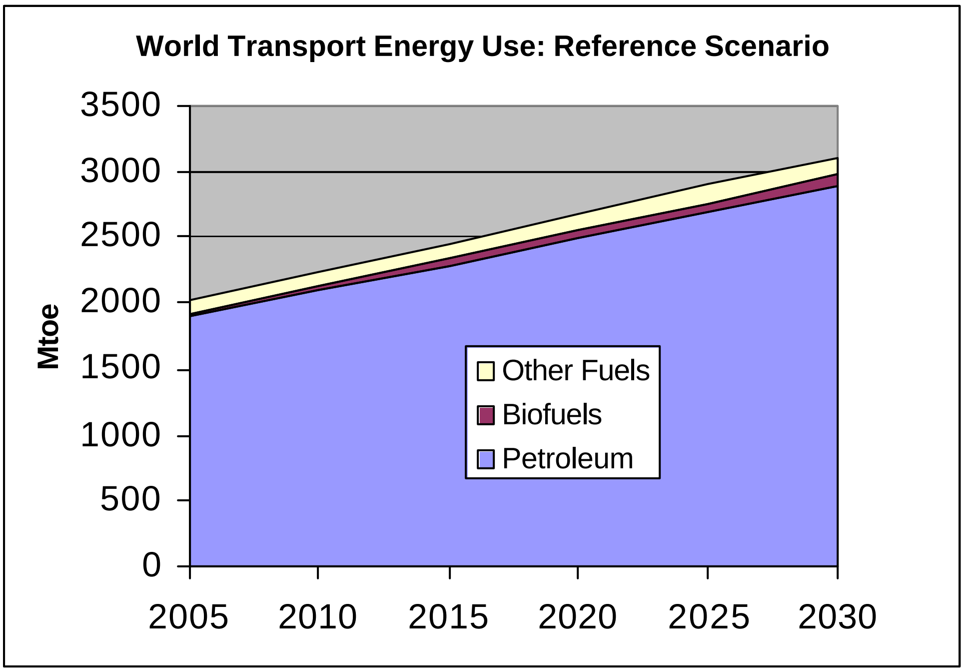


Figure 7. World Transport Energy Use by Mode in BAU Scenario

Transport CO_2 emissions increase from just over 5 gigatons in 2005 to 8 gigatons in 2030. Emissions increase in all regions but by far the greatest increases occur in the developing economies, followed by the OECD (Figure 8).

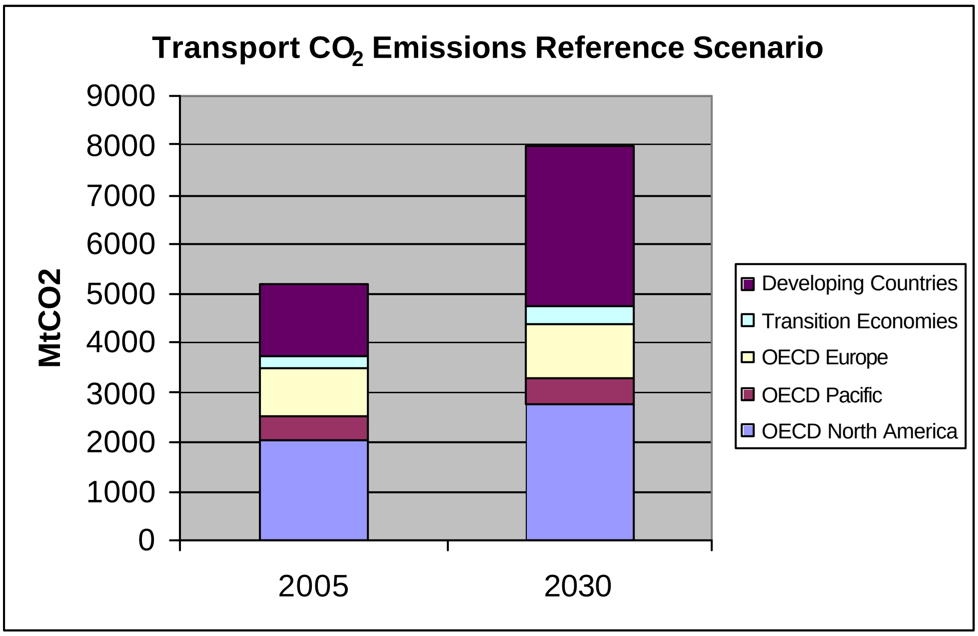


Figure 8. World Transport CO_2 Emissions in the BAU Scenario.

b. Investment needs for the reference scenario

Estimates of gross fixed capital formation (gross investment) in transport have been provided by the IEA for the reference scenario (table 1). It is noted that the total global GFCF estimated by IEA ($1.1 trillion US in 2002) is approximately twice that of the UN source, discussed above, for the year 2000 ($0.55 trillion US in 2000). In part this can be attributed to differences in the definitions of transport but it must be chiefly attributed to different data sources and estimation methods. The vast majority of investment is for "trade & transport", a category that includes infrastructure investments as well as all other transport equipment not considered road vehicles. Global gross investment in motor vehicles increases from $83 billion in 2005 to $190 billion by 2030, reflecting the expected growth in world motor vehicle supply and demand. The largest increases are expected in China, Japan, and East Asia, with more modest rates of increase but still very substantial increased investment in Europe and North America. Gross investment in transport and trade grows from $1.4 trillion to $3.7 trillion over the same period. The greatest increases come in China and India, but there are substantial requirements for increased investment throughout the world. Investments in trade and transport in Africa, for example, more than triple.

Table 1. Gross Investment in Global Transport by Region, 2005-2030, Reference Scenario.

Gross Fixed Capital Formation (Gross Investment) In Global Transport by Region, 2005-2030, Reference Scenario

(Billions of $US 2001 Dollars)

Motor Vehicles	2002	2005	2010	2015	2020	2025	2030
Australia & New Zealand	1.07	1.01	1.15	1.37	1.64	1.84	2.04
Japan	8.69	19.66	21.85	25.97	27.85	30.23	32.94
South Korea	1.71	2.31	2.85	2.90	3.39	4.05	4.61
Canada	2.84	3.17	3.22	3.68	4.28	4.82	5.45
Mexico	2.24	4.45	5.95	7.90	9.86	11.89	14.20
USA	9.94	9.48	10.39	11.78	13.15	13.64	14.44
Germany	9.62	8.25	8.59	10.02	11.31	12.35	13.53
Spain	0.16	0.41	0.51	0.55	0.64	0.70	0.75
France	2.47	3.82	4.37	5.31	6.24	7.05	7.91
UK	1.36	1.51	1.66	1.82	1.97	2.10	2.24
Italy	1.10	1.77	1.95	2.43	2.85	3.19	3.60
Rest of EU 15	3.08	3.89	4.13	4.98	5.86	6.62	7.33
Czeck Rep., Slovakia, Hungary	0.40	1.45	1.84	2.08	2.27	2.47	2.76
EFTA	-0.01	0.99	1.52	1.90	2.19	2.45	2.70
Poland	0.84	0.64	0.79	1.00	1.13	1.24	1.40
Turkey	0.66	0.57	1.04	1.32	1.70	2.13	2.62
Brazil	1.75	1.28	1.40	1.64	1.90	2.15	2.45
Russian Federation	1.15	1.23	1.64	2.12	2.50	2.89	3.44
India	1.41	1.89	3.02	4.37	5.80	7.27	8.80
Indonesia	1.59	1.12	1.72	2.30	2.97	3.66	4.36
China	6.77	7.97	14.15	18.77	23.19	27.37	30.89
South Africa	1.07	0.96	1.33	1.50	1.72	1.94	2.21
Central America	0.34	0.28	0.30	0.33	0.36	0.38	0.41
Rest of South America	-1.33	0.65	0.73	0.98	1.22	1.48	1.78
Rest of East Asia	2.99	2.79	4.23	5.69	7.37	9.21	11.32
Other South Asia	0.33	0.22	0.32	0.44	0.56	0.68	0.80
Taiwan	0.32	0.39	0.69	0.87	1.02	1.14	1.26
Rest of Europe	0.13	0.14	0.17	0.22	0.25	0.28	0.32
EU Member non-OECD	0.08	0.07	0.09	0.11	0.12	0.12	0.12
Other Ex-USSR	0.05	0.06	0.11	0.15	0.20	0.26	0.34
Middle East	-0.10	0.20	0.58	0.89	1.32	1.85	2.52
North Africa	0.17	0.18	0.23	0.32	0.43	0.55	0.73
Rest of Africa	0.02	0.01	0.02	0.03	0.05	0.06	0.09
Rest of South Africa	0.02	0.01	0.02	0.02	0.03	0.04	0.05
World subtotal, motor vehicles	62.9	82.9	102.6	125.8	147.4	168.1	190.4
Trade and Transport	2002	2005	2010	2015	2020	2025	2030
Australia & New Zealand	13.63	16.29	19.25	20.50	24.37	27.94	31.01
Japan	74.45	146.04	146.52	217.47	239.53	270.10	293.72
South Korea	12.98	18.09	22.69	26.42	31.19	36.67	40.44
Canada	18.10	23.51	26.82	31.26	38.23	44.81	50.57
Mexico	48.93	58.22	89.26	110.66	130.92	154.00	179.27

USA	207.55	308.29	367.44	396.18	454.97	503.09	546.12
Germany	42.59	48.66	55.78	63.92	72.81	82.12	90.56
Spain	56.53	67.09	81.01	89.61	98.76	109.83	121.47
France	27.84	40.37	49.18	55.28	63.39	71.63	77.48
UK	42.96	52.34	59.16	62.87	68.42	74.49	80.91
Italy	71.27	63.67	81.32	92.94	102.84	113.81	124.82
Rest of EU 15	63.51	70.09	85.96	100.42	115.29	130.15	144.79
Czeck Rep., Slovakia, Hungary	6.34	7.58	9.91	11.64	13.28	14.93	16.53
EFTA	11.37	15.45	21.09	23.39	26.14	29.37	32.34
Poland	13.93	13.90	19.57	23.48	25.19	26.88	28.78
Turkey	9.20	23.47	35.86	49.68	62.73	76.59	91.01
Brazil	4.59	6.20	5.28	6.52	8.23	10.22	12.28
Russian Federation	9.30	8.58	13.75	19.62	26.16	33.35	40.09
India	29.10	49.88	78.78	107.32	140.90	179.56	220.23
Indonesia	7.48	10.23	14.94	18.86	23.78	29.25	34.54
China	90.51	168.77	293.03	389.02	498.97	631.25	765.51
South Africa	5.08	6.65	8.05	9.75	11.27	12.96	14.80
Central America	9.48	8.57	9.38	10.10	11.23	12.61	14.19
Rest of South America	43.40	15.80	29.07	37.77	47.26	58.15	70.76
Rest of East Asia	26.34	40.20	58.80	76.10	94.83	115.84	137.77
Other South Asia	5.34	10.39	15.90	22.23	29.05	36.74	44.86
Taiwan	7.87	11.89	21.05	29.03	37.89	46.73	54.75
Rest of Europe	5.05	7.20	8.80	9.78	10.98	12.32	13.71
EU Member non-OECD	3.92	4.38	5.68	6.63	7.60	8.68	9.83
Other Ex-USSR	5.13	3.73	6.11	8.33	10.79	13.71	17.24
Middle East	36.82	25.29	53.89	78.76	104.74	135.74	172.25
North Africa	15.07	12.43	16.72	22.75	30.41	40.00	51.16
Rest of Africa	6.41	4.67	7.01	10.13	14.00	19.38	26.72
Rest of South Africa	2.26	2.82	4.12	5.70	7.68	10.47	14.29
World subtotal, trade & transport	1034	1371	1821	2244	2684	3173	3665
WORLD TOTAL TRANSPORT	1097	1454	1924	2370	2831	3341	3855

While investment in motor vehicles plus trade and transport triples from 2002 to 2030, investment in petroleum and coal products (much of which will go to producing transportation fuels and which includes investments to produce biofuels) will remain relatively constant at near $20 billion per year (table 2). This suggests that increased investments for biofuels as well as the growth in transport energy use are largely offset by reductions in demand for conventional petroleum fuels.

Table 2. Projected Transport-Related Investments in Reference (BAU) Scenario

Billions of 2001 US$	2002	2005	2010	2020	2030	Est. Cumulative
Motor vehicles	63	83	103	147	190	3,746
Petroleum and coal products	21	15	17	19	22	541
Trade and transport services	1,034	1,371	1,821	2,684	3,665	68,207

IV. Mitigation Scenario (BAPS)

The key options for mitigating transport's GHG emissions can be divided into five categories:

1. Vehicle efficiency
2. Low-carbon fuels
3. Transport pricing
4. Infrastructure and land use investments and regulation
5. Transport systems operation

The BAU scenario already contains a substantial amount of mitigation via vehicle efficiency improvement and to some degree incorporates other mitigation options discussed below. The mitigation scenario relies on increased use of biofuels, hybrid electric vehicles and further vehicle efficiency improvements.

Vehicle efficiency improvements include both vehicle technology and vehicle operation (IEA, 2005). Substantial opportunity exists to improve the energy efficiency of conventional vehicle technology, based on internal combustion engines utilizing liquid hydrocarbon fuels. Engine efficiency improvements on the order of up to a 20% reduction in fuel consumption should be achievable over the next decade or so by taking advantage of a variety of proven or near market-ready technologies (e.g., direct injection, turbo-charging with engine downsizing, variable valve timing and lift, variable displacement, engine-off-at-idle, friction reduction, etc. See, e.g., EEA, 2006; NRC, 2002; WBCSD, 2004). Near-term improvements to transmissions (e.g., 6-7 gear automatic transmissions, automated manual transmissions, continuously variable transmissions) have the potential to improve fuel economy by 5-10%. Making use of all conventional technologies EEA estimates a potential reduction in greenhouse gas emissions of 20-25%. The IEA (2006b) estimates that the fuel economy of gasoline vehicles could be improved by 40% by 2050.

Increased market penetration of hybrid vehicles is a key component of the Mitigation Scenario. By combining an electric motor, internal combustion engine and substantial energy storage, hybrid vehicles can improve fuel economy by an additional 15-20% over improved conventional ICE vehicles (EEA, 2006; EC/concawe/EUCAR, 2004). These advanced technologies increase the manufacturing costs of vehicles but reduce the energy costs of operating them. Current manufacturing costs for hybrid vehicles are estimated to be $2,000 to $3,000 greater than those of conventional vehicles. Given continued advances in battery, motor and controller technologies, future incremental costs are likely to be only about half that, $1,000 to $1,500 per vehicle (IEA, 2006, table 5.6; and Heywood, 2007). Vattenfall (2007) reports an expected cost of Euro 1,200 in 2030 with a range from Euro 600 to Euro 2,500. Using a 75% rule of thumb for investment as a share of manufacturing cost, a very round estimate of investment costs would be $1,000 per hybrid vehicle for the period after 2015.

The realized fuel economy of motor vehicles is affected by how they are driven and maintained. Speeding, aggressive driving behavior, excessive idling, improper tire pressure, even the choice of motor oil can affect on-road fuel economy. A recent study by the ECMT/IEA (2004) concluded that a 10% reduction in average fuel consumption per kilometer could be achieved for light-duty vehicles across IEA countries through a combination of measures. In-use fuel economy optimization could be a significant operational strategy for greenhouse gas mitigation.

Substitution of low-carbon fuels for petroleum also offers significant potential for GHG mitigation in transport. At present, the most significant non-petroleum, low-carbon transport fuels are ethanol and biodiesel from biomass and compressed natural gas. In comparing alternative transport fuels it is essential to include total fuel cycle emissions from "well to wheel". On this basis, the benefits of ethanol use vary greatly depending on the feedstock and conversion process. Farrell (2006) has estimated that on average, ethanol from corn as produced in the U.S. reduced well-to-wheel GHG emissions by only about 13%, on average. Ethanol from sugarcane as produced in Brazil, however, reduced fuel cycle GHG emissions by 80-90%. If much greater amounts of ethanol are to be used with significant GHG benefits, it will need to be produced from ligno-cellulosic biomass by processes whose market-readiness remains to be demonstrated. In the U.S. ethanol presently accounts for only about 3% of gasoline energy use, while in Brazil it makes up 30%. Biomass fuel production, however, is constrained by the availability of suitable land. It has been estimated that one third or more of transportation fuels worldwide could be displaced by biofuels in the 2050-2100 time frame (IEA, 2004). The potential for biofuel production, however, varies greatly across countries and regions.

Significant other options exist for mitigating transport GHG emissions via pricing of transport, efficiently operating transport systems, influencing the level of demand and modal structure of transport via infrastructure investments and land use planning and regulation. The mitigation potential of such options and their costs vary greatly across regions and countries. All such policies will require investment in both human and physical capital.

IPCC (Ribeiro and Kobayashi, 2007) provides a range of transportation mitigation marginal costs for 2050 based on the IEA report on advanced energy technologies (Figure 9). Although the quantitative data are provided only for 2050, an examination of table 3.5 in IEA (2006b) on which the estimates are based shows only small differences between the estimated potentials in 2030 and 2050. First, the mitigation potential appears to be much more modest than that assessed by Vattenfall for 2030. Second, all technologies with negative costs have been combined into the "less than $0" category, so that the left-hand portion of the curve is not apparent. The more modest mitigation potential can be largely explained by the fact that the IEA (2006b) report considers overwhelmingly technological options rather than systems, infrastructural, operational strategies included in other assessments. It is also because the report foresees limited market success before 2050 for technologies with the potential to radically decarbonizes transportation energy use, such as electric or hydrogen-powered vehicles.

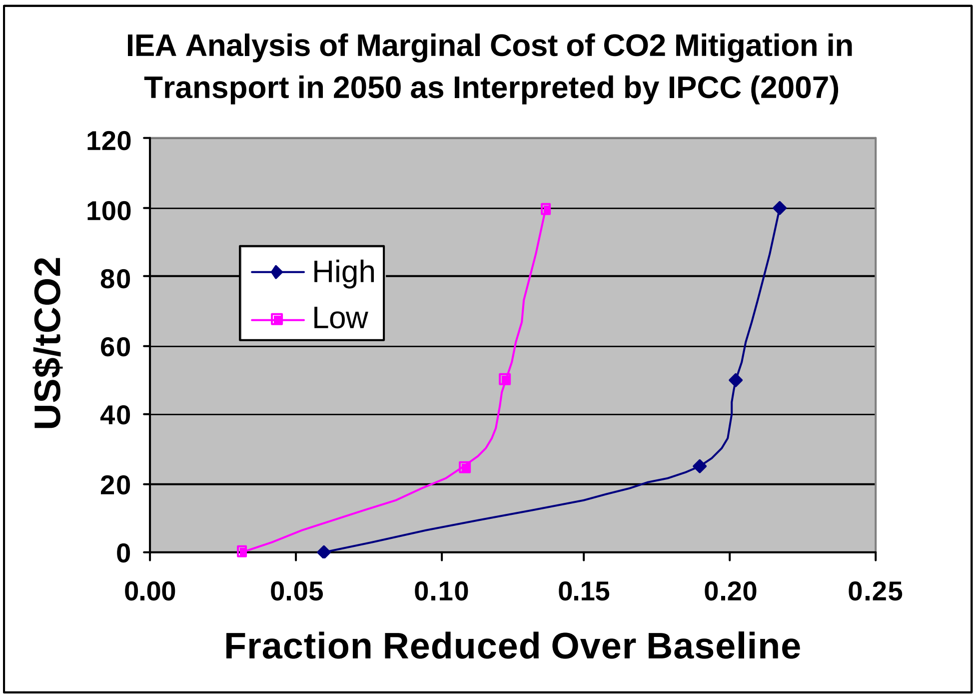


Figure 9. IPCC Assessment of IEA Marginal Mitigation Costs for Transport

Even mitigation opportunities with net costs less than zero will require some degree of investment to be realized. Unfortunately, the necessary investment costs are rarely estimated for the transport sector by analysts.

A recent study by the Center for Clean Air Policy (2006) produced the marginal abatement cost estimates shown in figure 10 for China, India and Brazil. For China, the abatement technologies consisted primarily of vehicle technologies that were judged to have negative abatement costs. Bus rapid transit and low-carbon fuel switching had positive marginal costs. For India, the low-cost options were modal shifts from road to rail transport, increased use of public transport, rail electrification, and fuel switching to compressed natural gas. Vehicle efficiency improvements and use of biodiesel were judged to have marginal costs greater than zero. The Brazilian assessment did not consider increased use of bio-ethanol from sugar cane, but vehicle efficiency, fuel economy labeling and biodiesel. This explains the very large difference in mitigation potential as estimated by the CCAP study and the IEA WEO BAPS scenario. All of these mitigation options, including those with negative marginal costs, will require investment to be realized.

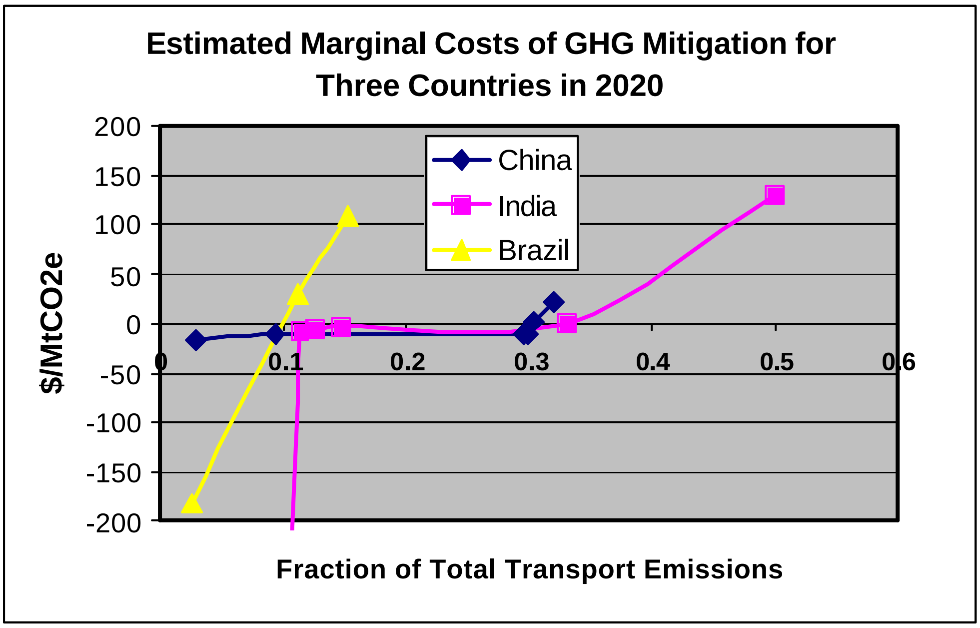


Figure 10. Marginal Costs of GHG Mitigation from Transport for Three Countries (CCAP, 2007)

a. Energy consumption and mix, GHG emissions

The IEA's Alternative Policy Scenario measures the mitigation that could be achieved if countries were to adopt all the policies they are currently considering to reduce oil dependence and CO_2 emissions. To this the BAPS adds a greatly increased market share for hybrid vehicles, a doubling of biofuel use, and the advent of new technologies such as plug-in hybrid vehicles. These policies are expected to speed the development and deployment of more efficient vehicle technologies and low-carbon fuels. For example, new vehicle fuel economy standards in the United States are projected to raise new vehicle average fuel economy by 31% over the BAU Scenario by 2030. Fuel efficiency standards in Japan, the EU and China are met and prolonged. In the EU, the emissions trading scheme is extended to include civil aviation. All of these countries, as well as India and Brazil expand their use of biofuels in transport in the BAPS Scenario. As a consequence, total transport energy use increases from 2.00 Gtoe in 2005 to 2.66 Gtoe in 2030, an average annual growth rate of 1.15%, 0.61%/year lower than in the BAU Scenario. In addition, biofuel use expands rapidly eroding to a modest extent petroleum's dominance as transport's main source of energy (Figure 11).

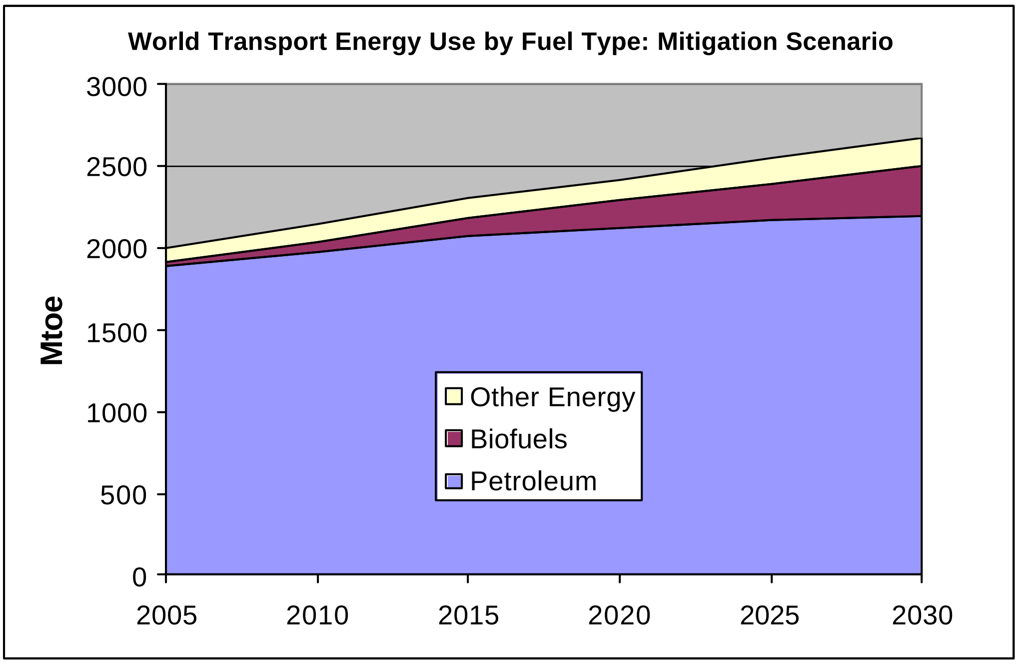


Figure 11. World Transport Energy Use by Fuel Type in the Mitigation Scenario.

Biofuel use in transport increases greatly in both the OECD and developing economies (Figure 12). OECD use increases by a factor of 13 from 13.0 Mtoe in 2005 to 168.5 Mtoe in 2030, a difference of 155 Mtoe. In developing and transition economies, transport biofuel use grows by more than 17-fold from 8.0 to 140.9 Mtoe, an expansion of 133 Mtoe. While most of the growth occurs in Brazil, there are also significant increases in India, Indonesia, China, and other developing Asia. Still, transport CO_2 emissions increase, driven by the growth of motorized transport in developing economies (Figure 13).

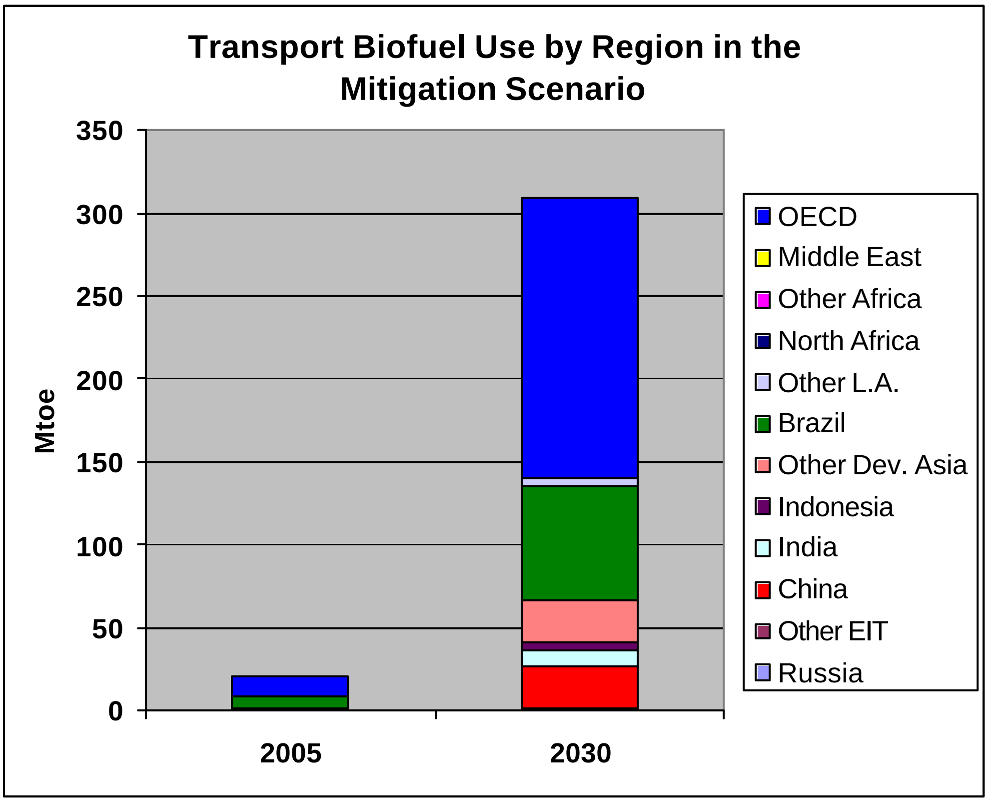


Figure 12. Transport Biofuel Use by Region in the Mitigation Scenario

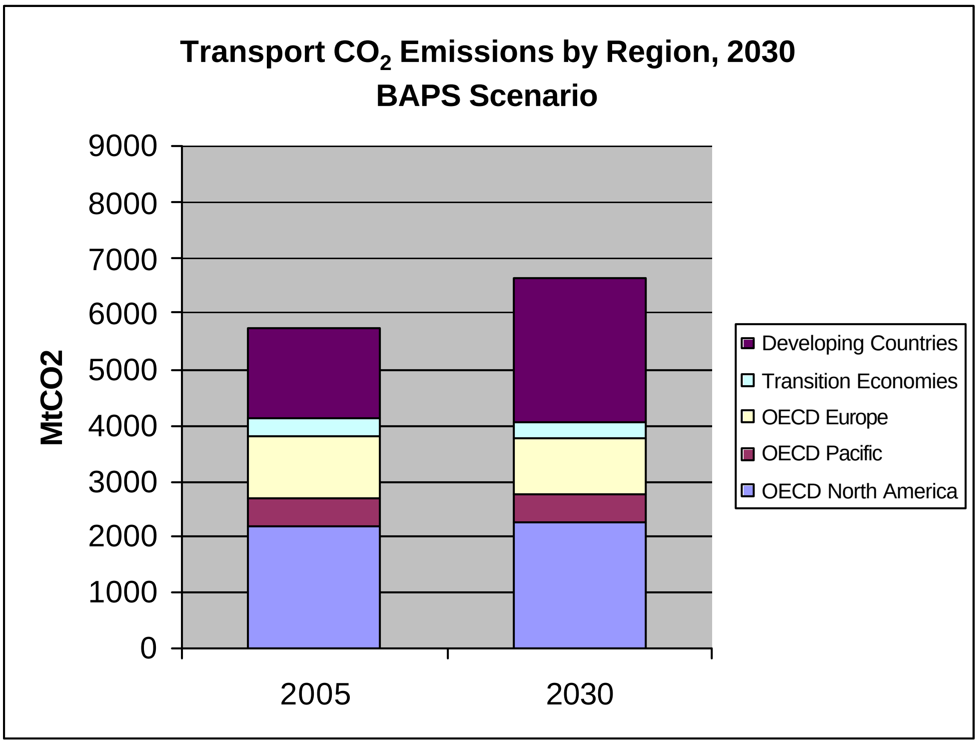


Figure 13. World CO2 Emissions from Transport in the Mitigation Scenario.

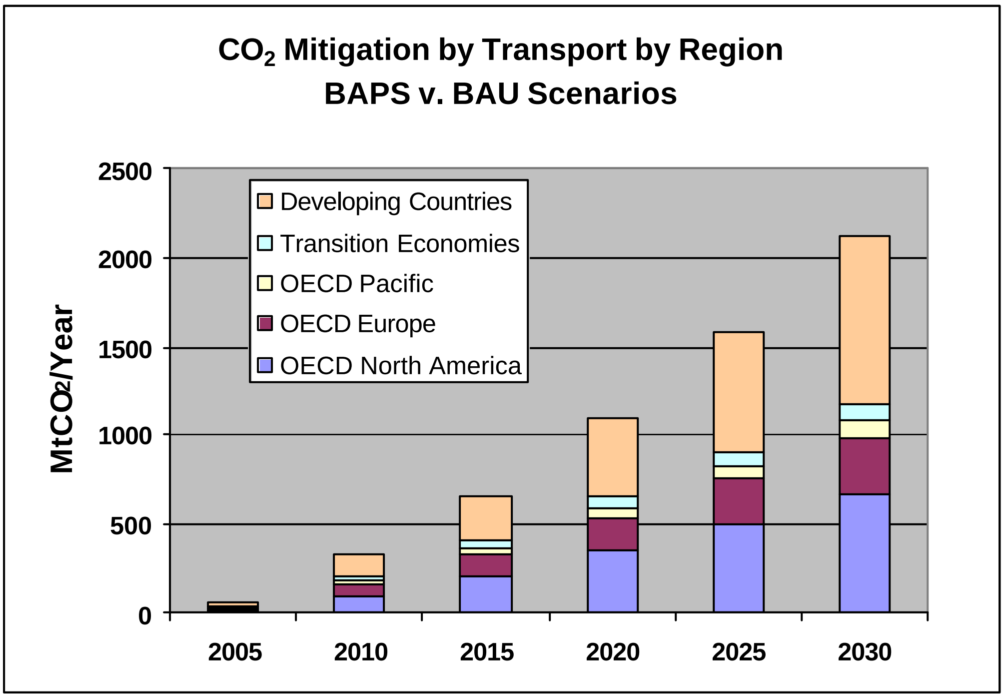


Figure 14. Global Transport CO2 Mitigation by Region, BAU v. Mitigation Scenario.

Global greenhouse gas mitigation rises from 0.3 gigatons of CO_2 equivalent to 2.1 gigatons by 2030 (Figure 14). In 2030, 661 million tons is achieved by OECD North America, 323 million tons by OECD Europe, but the largest reduction, 936 million tons, is accomplished by developing countries. The remainder of the world, transition economies and OECD Pacific combine for 192 million tons.

b. Investment needs for the mitigation scenario

In general, studies of transport's GHG mitigation potential have not addressed investment requirements. Nonetheless, several kinds of investments will be necessary to realize the potential to reduce GHG emissions from transport. For countries with vehicle manufacturing capacity, the investments will be in the form of R&D, human capital (for engineering and maintenance), and capital (retooling and maintenance). For countries without domestic manufacturing capacity, investment will come in the form of increased upfront vehicle purchase costs and in human capital for the maintenance of generally more complex engine and transmission systems. Infrastructure investments, e.g. for public transit systems or improved traffic control, will also be required. The need for investment in human capital for policy formulation and analysis should also not be neglected. For example, donor agencies played a significant role in developing the in country analytical capabilities utilized by China in establishing its motor vehicle fuel economy standards.

Total increases in investment for transport mitigation in the APS and BAPS scenarios were obtained from the OECD GREEN model. These show the majority (US$2.0 trillion) of the investment going into vehicle efficiency improvements, hybrid and plug-in hybrid vehicles versus US$0.24 trillion into biofuels (table 3). Also shown in table 3 is the reduction in investment requirements for fossil fuel supply. These numbers include more than petroleum, however, because the BAPS reduces petroleum use by aboutn 15 mb/d over the Reference Case, and petroleum accounts for approximately 40% of primary energy demand in the Reference Scenario, it is clear that reduction in transport's energy demand is responsible for a sizeable share of the reduction in fossil fuel supply investment.

Table 3. Estimated Global Gross Investment for Transport Mitigation in BAPS, 2005-2030 (Billion 2001 US$)

	Transport Efficiency	Biofuels	Fossil Fuel Supply
Reference to APS Scenario	1076	64	-874
APS to BAPS	970	175	-732
TOTAL	2046	239	-1606

Source: OECD GREEN model outputs, personal communication Xiaohua Zhang, 02 July, 2007.

The total changes in transport efficiency investment shown in table 3 can be allocated to regions based on each region's share of total, cumulative gross capital formation in the Reference Scenario (Table 1). The allocation can be made based on either motor vehicle investment or trade & transport investment (or both). Table 4 shows the allocations based on the two methods. Allocation based on motor vehicle investments is believed to be the more appropriate method since the great majority of transport mitigation in the BAPS is achieved by motor vehicle efficiency improvements.

Table 4. Estimated Regional Shares of Global Transport Efficiency Investments to 2030.

Estimates of Transport Mitigation Investment for BAPS				
	Total Gross Investment 2005-2030		Estimated Mitigation Investment	
	Motor Vehicles	Trade & Transport	Motor Vehicles	Trade & Transport
	Cumulative, Undiscounted Billion $US 2001			
Australia & New Zealand	37.7	578.5	**22.7**	*19.0*
Japan	661.1	5467.5	**397.5**	*179.8*
South Korea	83.3	731.2	**50.1**	*24.1*
Canada	101.5	890.8	**61.1**	*29.3*
Mexico	224.6	3017.9	**135.1**	*99.3*
USA	304.6	10744.4	**183.2**	*353.4*
Germany	265.8	1721.2	**159.9**	*56.6*
Spain	14.9	2367.4	**9.0**	*77.9*
France	144.1	1492.0	**86.7**	*49.1*
UK	47.2	1657.8	**28.4**	*54.5*
Italy	65.5	2425.8	**39.4**	*79.8*
Rest of EU 15	136.0	2696.3	**81.8**	*88.7*
Czeck Rep., Slovakia, Hungary	53.8	309.0	**32.4**	*10.2*
EFTA	49.6	619.4	**29.8**	*20.4*
Poland	25.9	582.2	**15.6**	*19.2*
Turkey	38.9	1410.5	**23.4**	*46.4*
Brazil	44.8	197.4	**26.9**	*6.5*
Russian Federation	57.4	586.0	**34.5**	*19.3*
India	129.0	3208.1	**77.6**	*105.5*
Indonesia	67.0	546.1	**40.3**	*18.0*
China	514.6	11397.1	**309.5**	*374.9*
South Africa	40.3	263.7	**24.3**	*8.7*
Central America	8.6	273.5	**5.2**	*9.0*
Rest of South America	28.1	1077.6	**16.9**	*35.4*
Rest of East Asia	167.8	2172.8	**100.9**	*71.5*
Other South Asia	12.6	657.7	**7.6**	*21.6*
Taiwan	22.7	840.1	**13.7**	*27.6*
Rest of Europe	5.8	261.7	**3.5**	*8.6*
EU Member non-OECD	2.7	178.5	**1.6**	*5.9*
Other Ex-USSR	4.6	247.2	**2.8**	*8.1*
Middle East	30.0	2359.5	**18.1**	*77.6*
North Africa	9.9	708.4	**6.0**	*23.3*
Rest of Africa	1.1	331.1	**0.7**	*10.9*
Rest of South Africa	0.7	182.6	**0.4**	*6.0*
-				
TOTAL	3402.2	62200.9	2046.0	2046.0

An alternative method for making rough estimates of mitigation investment requirements has been implemented to develop estimates based on Vattenfall's transport mitigation analysis. Without further refinement, this method is believed by the author to be accurate only to order of magnitude. The estimates are presented to provide an alternative viewpoint. The estimates based on the OECD Green model shown in tables 3 and 4 above are considered by the author to be the more reliable.

The premise of the method is that marginal abatement costs are approximately proportional to the investment required to achieve abatement. A plausible underlying model would be that investment costs are approximately a constant fraction of total abatement costs. If this is true, then total costs can be calculated by integrating the marginal abatement cost curve. Unfortunately, the fraction of total abatement costs that investment represents is not known. However, most abatement comes from vehicle technology or low-carbon fuels. Both the vehicle manufacturing and energy industries are capital intensive (energy more so than vehicles). In addition, investments must be made in human, as well as physical capital, further increasing the share of investment costs in total costs. It is here assumed that investment in physical and human capital comprises 75% of total abatement costs.

Vattenfall's analysis of abatement opportunities states that, "The adoption of alternate fuels such as bioethanol and biodiesel can achieve abatement levels of 1.2 Gt CO_2e, at zero or close to zero cost. Nonetheless, development of biofuel production capacity will require investment. An alterntative method, described below, is used to separately estimate the investment costs for biofuels by region. Estimates based on the Vattenfall curve are assumed to apply to conventional vehicle efficiency improvements and adoption of hybrid vehicles. The efficiency and biofuel estimates will be added to obtain an overall estimate of mitigation investment costs.

A straight line marginal cost function was fitted to Vattenfall's estimated marginal abatement costs for transport in 2030 (Figure 14). Cumulative reductions in MtCO2e/year were converted to percent reductions from the BAU scenario level for global emissions in 2030 (8742 million tons CO2). Because the Vattenfall MC curve estimates costs in tons per year, the estimated investment costs should be interpreted as annual costs. Clearly, Vattenfall's data are non-linear, yet the linear function was chosen because its simplicity is believed to be more consistent with the crudeness of the overall method. A fitted logistic function is also shown in Figure 14. Vattenfall's analysis extends up to 2.85 gigatons of greenhouse gases mitigated in the global transport sector. At that point, costs turn up dramatically, increasing from EUR40/CO_2e at 2.5 gigatons to EUR675/tCO_2e at 2.84 gigatons. Figure 14 also shows least squares fits of linear and three-parameter logistic functions to the Vattenfall data. Over the range of interest (from zero to 2.84 gigatons), the linear function fits almost as well as the logistic function, although the Vattenfall data show much lower costs between 1.5 an 2.45 gigatons.

The Vattenfall MC curve shows negative abatement costs up to almost 1,500 MtCO2/yr. Negative costs occur because the value of energy saved and ancillary benefits of reducing carbon fuel use more than pay for the initial cost. This does not imply negative investment. If it is assumed that for the most cost-effective technology the present value of future benefits is twice the cost, then the intercept of the straight line MC function becomes zero, as illustrated in Figure 14 by the blue line. Since this is assumed to be the marginal expenditure function, integrating it from zero to the fractional mitigation achieved gives an estimate of total expenditure and 75% of total expenditure is assumed to be investment.

Vattenfall (2007) estimates that the 2006 IEA WEO BAU scenario contains 1.5 gigatons of mitigation in comparison to a "frozen technology" scenario in which activity levels increase as in the BAU scenario but carbon emissions rates are frozen at the base year level throughout the scenario. The estimated total expenditures on mitigation are about 65 billion Euros, leading to an estimate of 50 billion Euros of investment in mitigation. For a rough sense of magnitude, this compares with $3.75 trillion 2001 US$ invested in motor vehicle manufacturing over the same period (table 1). No estimates of mitigation by country or region are available and so no disaggregation by region has been made. Mitigation estimates by region and for selected countries are available for the Mitigation scenario and are presented below.

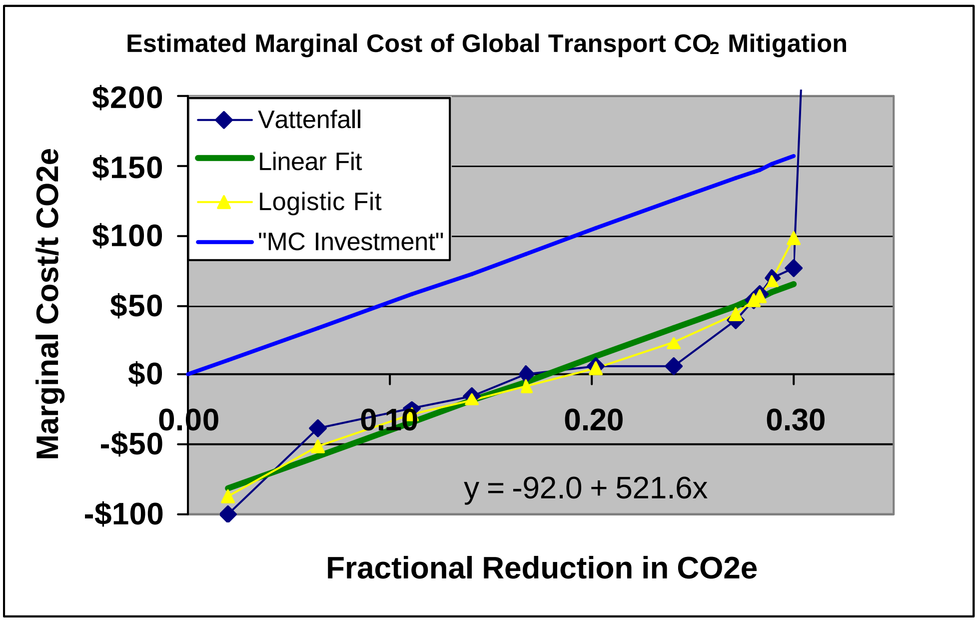


Figure 14. Alternative Marginal Cost Functions for Global Transport GHG Abatement (Based on Vattenfall, 2007)

Transportation investment needs were estimated by applying the marginal cost curve derived from Vattenfall (2007) described above to estimate the global mitigation total and sharing the total cost to regions and countries in proportion to their share of total global mitigation. Again, since Vattenfall's analysis shows that use of biofuels has zero or close to zero cost, investment costs for biofuels development are estimated separately. Sharing in this way implies that each country mitigates transportation emissions up to the global marginal mitigation cost. This presumes economically efficient mitigation by all nations. In the absence of other information, this was judged to be the most appropriate assumption. The fraction of greenhouse gases mitigated varies moderately across countries and regions with the exception of Brazil, reflecting the exceptional ability of that country to produce biofuels that are both cost-effective and low in well-to-wheel greenhouse gas emissions (Figure 15). The moderate variability of mitigation potentials across countries and regions indicates similar mitigation cost functions, assuming that each country reduces emissions up to the same marginal mitigation costs.

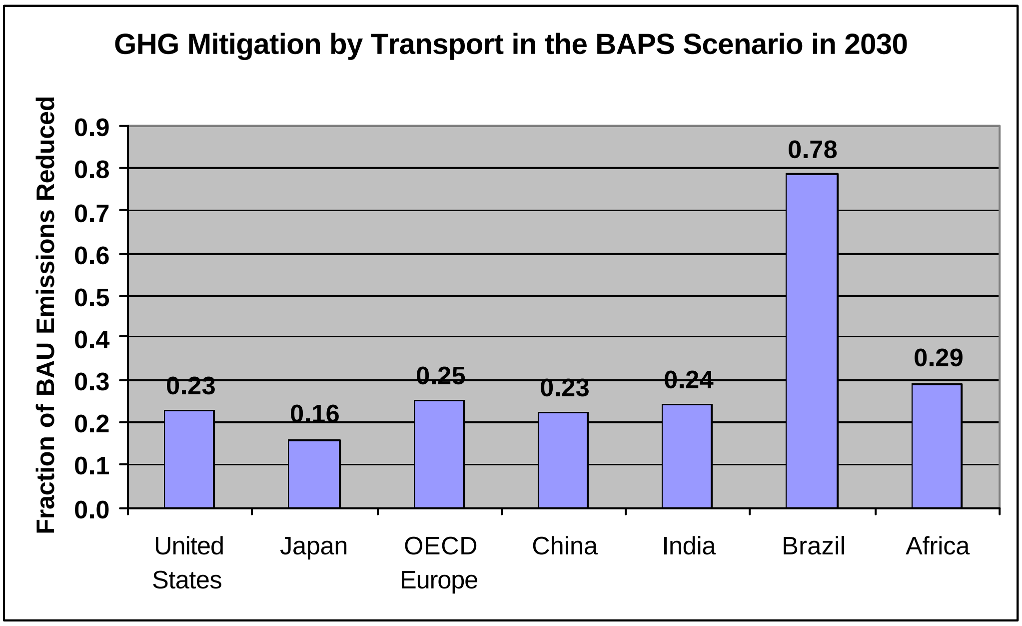


Figure 15. Fractional Reduction in GHG Emissions Across Countries in Mitigation Scenario.

Total annual investment costs for global transport GHG mitigation in 2030 are estimated to be approximately Euro 130 billion. This is not an estimate of the cumulative investment required from 2005 to 2030 but rather the investment for the year 2030 only. The Vattenfall MC curve describes the relationship between the cost per ton of CO_2 per year and tons of CO_2 mitigated per year. Thus, the estimate of 130 Euros should best be interpreted as the capital charge for the mitigation accomplished in 2030.

The allocation of estimated investment costs to regions and countries is shown in table 5. The first column shows the estimated capital charge for incremental efficiency investments, estimated using the Vattenfall data and the methods described above. The estimated capital charge can be translated into an estimated incremental capital investment in place by assuming a uniform capital charge rate of 10% across all countries. Certainly, capital charge rates will vary across nations and regions. The estimates presented in table 3 must be considered very rough.

It is not surprising that the OECD countries have the largest investment requirements. It may be surprising that the investment needs of developing economies appear to be almost equally large, 59 billion Euro for the mitigation achieved in 2030. Estimates for China and India come in at 16 billion and 4 billion Euro, respectively. Latin America and Africa are estimated to require investment levels of 17 billion and 8 billion Euro for 2030, respectively. It is important to bear in mind that these estimates are very rough, and are based on the assumption that marginal abatement costs are equalized across countries. Nonetheless, the do suggest that the investment needs of developing economies for the levels of GHG mitigation shown in the IEA scenarios will be comparable to those of the entire OECD.

Table 3. Estimated Investment Requirements for Transport GHG Mitigation in 2030

Country/Regions	Estimated Capital Charge (Billions of Euro)	Estimated Investment in Place (Billions of Euro)
World	$133	$1,331
OECD	$68	$682
OECD North America	$42	$416
United States	$35	$351
Canada	$3	$26
Mexico	$4	$40
OECD Pacific	$6	$62
Japan	$3	$30
Korea	$2	$18
Australia and New Zealand	$1	$13
OECD Europe	$20	$204
Transition Economies	$6	$60
Russia	$4	$38
Other EIT	$2	$21
Developing Countries	$59	$590
Developing Asia	$30	$302
China	$16	$157
India	$4	$36
Indonesia	$2	$22
Other Developing Asia	$9	$87
Latin America	$17	$171
Brazil	$12	$120
Other Latin America	$5	$51
Africa	$8	$77

Assumes a capital charge rate of 10% across all countries.

The estimated 133 billion Euro ($173 billion US) incremental capital charge for investment in 2030 is interpreted to exclude biofuels but include all efficiency improvements, including hybrid vehicles. The additional cost of FFVs is also presumed to be included. The mitigation scenario assumes a near total replacement of conventional gasoline vehicles with mild and full hybrid vehicles by 2030. The share of conventional gasoline vehicles drops from 75% in the Reference Scenario to 5% in the Mitigation Scenario (table 3). The market share of diesel vehicles declines slightly, from 18% to 17%. The difference is made up by mild and full hybrid vehicles, whose market share increases to 76% from 7% in the Reference Scenario. All gasoline-using vehicles, whether hybrid or not, are assumed to be fuel flexible vehicles capable of using a blend of up to 85% ethanol and gasoline, at an incremental investment cost of $100 per vehicle. Assuming that retail prices are 50% greater than manufacturing costs and that 75% of the incremental manufacturing cost represents investment, the total investment requirements for hybrid, diesel and FFV vehicles in the Alternative Policy Scenario are the sum of the final column in table 6, or 62 billion dollars.

Table 6. Estimated Prices, Costs and Incremental Investment Requirements for Advanced Light-Duty Vehicles in Alternative Policy Scenario.

Estimated Prices, Manufacturing Costs and Investment Requirements of Advanced Light Vehicle Technologies in 2030

Technology Type	Price	Difference in Price	Cost	Investment US $/ vehicle	2030 Share Reference	2030 Share Mitigation	Change (10^6 Vehs)	Investment (10^9 US $)
	(US $ 000)							
Conventional Gasoline	$16.2	$0.0	$0.0	$0	75%	5%	-64.4	$0
Diesel	$17.5	$1.3	$0.9	$650	18%	17%	-0.9	-$1
Mild Hybrid Gasoline	$17.7	$1.5	$1.0	$750	7%	58%	46.9	$40
Full Hybrid Gasoline	$18.7	$2.5	$1.6	$1,225	0%	14%	12.9	$17
Full Hybrid Diesel	$19.4	$3.2	$2.1	$1,600	0%	4%	3.7	$6
FFV	$16.4	$0.2	$0.1	$100	Na	na	na	na

Source: IEA, 2006b, tables 5.2, 5.4, 5.5, 5.6; IEA 2006a, Ch. 9.

Comparison of increased transport biofuel use with increased biomass production by region in the Mitigation Scenario indicates that most or all of each region's transport biofuel is locally produced. Thus, investment requirements for biofuel production in developing economies will be of the same magnitude as investments in the OECD. IEA (2004) provides estimates of biofuel capital and production costs for the US, EU and Brazil (table 4). Vattenfall (2007) reports much lower costs for cellulosic ethanol in 2030: costs fall from $0.50-$0.60/liter of gasoline equivalent through 2015 to less than $0.30/liter gasoline equivalent in 2030. This would imply capital costs on the order of $0.11/liter, rather than $0.18/liter of ethanol. The estimates show considerable variation in capital costs by process and region. By multiplying the capital cost per liter by the annual biofuel production (converted to liters) provides an estimate of the capital charge per year rather than the cumulative investment cost. The total difference in investment cost for 2030 between the BAU and Mitigation Scenarios is obtained by multiplying the increase in transport biofuel use by the capital cost per Mtoe divided by an assumed capital recovery factor of 0.12. The increased production in all regions is assumed to be from ligno-cellulosic feedstock, with the exception of Brazil, where continued production from sugar cane is assumed.

The resulting estimate of total investment required for biofuels production is US$315 billion, of the same general magnitude of the IEA estimate of $239 billion. The very substantial differences in the cost of ethanol produced from ligno-cellulosic biomass reflect genuine uncertainty about future production costs. Not only are capital cost estimates uncertain but it is not clear at this time that producing ethanol from biomass is the most advantageous option. Biomass can be used to produce other alcohols and, via gasification and Fischer-Tropsch synthesis, it can produce conventional liquid hydrocarbon fuels, as well. As a consequence, both sets of investment cost estimates should be considered accurate to at best +/- 50%.

Table 4. Capital and Production Costs for Ethanol by Region and Process

Capital and Production Costs for Ethanol/Biofuel Production by Region (IEA, 2004, Ch. 4)

	(2004 US $/Liter)		
	Capital Cost	Cost per Liter	Cost/Gasoline Equivalent Liter
Cellulosic Ethanol US	$0.18	$0.36	$0.53
Corn Ethanol, US	$0.05	$0.29	$0.43
Beet/Wheat Ethanol, EU	$0.11	$0.51	$0.77
Sugar Cane Ethanol, Brazil	$0.05	$0.23	$0.34

Estimated Biofuel Investment Costs for the Mitigation Scenario.

	BAU	Mitigation (Mtoe)	Increase	Increase (B Liters)	Investment (B US $)
Russia	0.3	1.0	0.7	1.2	$1
Other EIT	0.0	0.0	0.0	0.0	$0
China	7.9	26.1	18.2	32.6	$30
India	2.4	8.9	6.5	11.7	$11
Indonesia	1.5	4.6	3.1	5.6	$5
Other Dev. Asia	4.3	25.9	21.7	38.9	$36
Brazil	20.3	68.9	48.6	87.0	$37
Other L.A.	0.0	4.3	4.3	7.6	$3
North Africa	0.0	0.0	0.0	0.0	$0
Other Africa	0.0	0.0	0.0	0.0	$0
Middle East	0.5	1.1	0.6	1.1	$1
OECD	51.7	168.5	116.7	209.1	$192
World	89.0	309.3	220.4	394.8	$315

To estimate the total incremental investment required for the mitigation scenario for the year 2030 would require converting the annual capital charge for efficiency and other non-biofuel measures (US $173 billion) into total investment. If one assumes the capital charge is approximately 10% of the total investment, then the estimated cumulative investment would be $1.7 trillion. Adding to this the total capital investment for biofuels production (US $315), produces a total estimate of approximately US $2 trillion. This is comparable to the *cumulative* investment needs for 2005 to 2030, based on IEA data shown in tables 3 and 4. In any case, the IEA estimates are believed to be more reliable since they are the product of direct modeling of the processes involved. The estimates based on Vattenfall's analysis should be considered a rough corroboration of the IEA estimates derived from an entirely different method and data source.

V. Comparison of the BAU and mitigation scenarios and identification of investment gaps.

As noted above, nearly all investment in motor vehicles and transport fuels is made by the private sector, while governments play the largest role in infrastructure investments. The available information is not adequate to determine whether or not investment gaps will exist for the mitigation scenario. However, a recent assessment of approaches to financing development and climate strategies (Dave et al., 2005) concluded that mainstream financing mechanisms would not always be sufficient and therefore incremental resources (public, private, national and international) will be needed. The study proposed five strategies for filling the investment gaps.

- National policies to attract new private capital.
- National policies to free public money for sustainable development investments by improving the efficiency of public investment.
- Integration of climate friendly development strategies in Official Development Assistance (ODA).
- International Financial Institutions integrate climate strategies into poverty reduction strategies and finance because of positive effects.
- Creation of a multilateral climate trust/climate fund that can help influence the choice of development pathways by countries.

Investment needs of two types should be considered. The data above focus on investment needs for capital formation. These investments will occur where production is located, be it vehicle or fuel production. However, there will also be increased expenditure requirements for more expensive vehicles or fuels where consumption is located. In the case of biofuels, production and consumption are likely to be collocated, as a general rule. Motor vehicle production and sales also will be substantially collocated, however, some developing economies will not have indigenous vehicle production but will have increased expenditures on vehicle purchases if they follow the BAPS trend to advanced technology vehicles. These countries will also require investments in physical and human capital for the repair and maintenance of advanced technology vehicles. The data presented in this report shed little light on this issue and further analysis is required.

It does not appear likely that the Clean Development Mechanism (CDM) of the Kyoto Protocol will provide adequate financing for transportation mitigation in developing economies (Dave et al., 2005, ch. 3). Transport CDM projects have been slow to get started and are far to few in number to have the necessary impact. As noted above, GEF projects to date have been tiny in relation to future mitigation investment needs.

VI. Assessment of needed changes in financial and policy arrangements

The investment requirements for the BAPS mitigation scenario are very large in relation to current financial assistance from donor countries. In the developing economies, investment requirements to achieve the BAPS probably exceed half a trillion dollars through 2030. With total ODA for transport standing at just over $10 billion per year, ODA over a 25 year period is not small in relation to mitigation investment needs. But this assistance is directed at a wide range of transportation investements traditionally unconnected to greenhouse gas mitigation. By continuing and expanding efforts to "mainstream" climate strategies into ODA for transport a significant impact might be achieved.

To date, direct assistance aimed at energy efficiency or promoting low carbon fuels in developing economies has been miniscule. Expanding these efforts by an order of magnitude could put them in position to make a significant contribution to future mitigation efforts.

In the end, most of the investment in transport mitigation in developed and developing economies will come from the private sector. To achieve the energy efficiency and biofuel goals of the BAPS, substantial investments in human capital and institutional capabilities will be required. Advanced energy efficiency technologies such as hybrid vehicles will require not only engineering expertise for design and fabrication but for maintenance, as well. There will be a need not only to foster the conditions for market acceptance of advanced technologies and low-carbon fuels, but also for in-country expertise in the formulation and analysis of policies to support them.

VII. Conclusions

Although the available data and methods have important limitations resulting in substantial uncertainty about mitigation investment needs (further analysis of the subject is warranted), it is clear that investment flows for transport mitigation will have to be greatly increased if the goals of the BAPS scenario are to be met. In the developed economies, investment requirements for mitigation are not large in relation to GFCF in the transport sector and it seems very likely that funding for mitigation will be forthcoming, especially given the savings in energy expenditures that can be achieved by more energy efficient transport. On the contrary, the outlook for mitigation investment in the developing world appears difficult.

Moreover, sources directed at environmental improvement and climate change, such as the GEF and CDM have thus far had minimal impact in the transport sector and would have to be increased by an order of magnitude or more to take on a meaningful share of the estimated future investment needs for transport mitigation.

Despite the fact that existing estimates of mitigation investment needs are incomplete and probably only accurate to +/- 50%, the data are adequate to support the broad conclusions stated above. However, a great deal of further analysis is needed to improve the accuracy of country-specific mitigation investment needs, to better delineate the possible roles of private and public investments, and to better understand the investments in human capital and institutions that will be needed to sustain advanced vehicle technologies and low carbon fuels in developing economies.

References

1. Borken J, Steller J, Meretei T and Vanhove F. 2007. Global and country inventory of road passenger and freight transportation, their fuel consumption and their emissions of air pollutants in the year 2000, presented at the 86th Annual Meeting of the Transportation Research Board, January 2007, Washington, DC, USA.
2. Dave, R., T. Heller, M.T.J. Kok and P.R. Shukla, 2005. “Financing Integrated Development and Climate Strategies”, Report 500019002/2005, Netherlands Environmental Assessment Agency, Bilthoven, Netherlands.
3. Energy and Environmental Analysis, Inc. (EEA). 2006. *Technologies to Reduce Greenhouse Gas Emissions from Light-Duty Vehicles*, report to Transport Canada, Ottawa, Ontario, Canada, March, 2006.
4. European Commission/concawe/European Council for Automotive R&D (EC/concawe/EUCAR). 2004. *Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context*, WELL-to-WHEELS Report, Version 1b, January 2004. Available at: http://ies.jrc.cec.eu.int/Download/eh .
5. European Council of Ministers of Transport/International Energy Agency (ECMT/IEA). 2004. *Technology and Policies to Improve Vehicle In-Use Fuel Economy*, OECD, Paris.
6. International Energy Agency (IEA). 2006a. *World Energy Outlook 2006*. Paris, OECD/IEA.
7. International Energy Agency (IEA). 2006b. *Energy Technology Perspectives 2006: Strategies and Scenarios to 2050*, OECD/IEA, Paris.
8. International Energy Agency (IEA). 2004. *Biofuels for Transport*. Paris, OECD/IEA.
9. International Energy Agency (IEA). 2005. *Saving Oil in a Hurry*, OECD, Paris.
10. National Research Council (NRC). 2002. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*. National Academies Press, Washington, D.C.
11. Ribeiro SK and Kobayashi S. 2007. Transportation and its infrastructure. Chapter 5 in IPCC Fourth Assessment Report, Working Group III.
12. Vattenfall AB. 2007. “Global Mapping of Greenhouse Gas Abatement Opportunitites up to 2030: Transport sector deep dive”. (Unpublished report, January, 2007).
13. World Business Council for Sustainable Development (WBCSD). 2004. *Mobility 2030: Meeting the challenges to sustainability*. Hertfordshire, England, UK, WBCSD. Also available at: <http://www.wbcsd.org/web/mobilitypubs.htm>