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# ALTERNATIVE TRAJECTORIES FOR DECARBONIZING URBAN TRANSPORTATION

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## Key Points

- ***The transportation sector is a major contributor to global greenhouse gas emissions, accounting for one-quarter (≈7 $GtCO_2$) of present day annual releases, 75% of which come from road transportation.***
- ***Unless there is a major effort to change current energy consumption patterns, transportation carbon emissions are projected to double by 2050 relative to 2010 levels. The mitigation potential for light duty vehicles in 2050 is ≈5 $GtCO_2$ at a carbon cost of 26 $\$_{2006}$ per tonne of $CO_2$.***
- ***According to our simulations, to achieve significant carbon emission reductions in the transportation sector by 2050 it will be necessary to reduce the demand for passenger cars, improve vehicle efficiencies, increase share of electric vehicles, and decarbonize electricity supply through the use of renewables, carbon capture technologies, and/or nuclear energy.***

A reliable, efficient and cheap transportation system is essential to social development and economic growth. The rapidly increasing worldwide demand to move people and goods is outpacing the available transportation infrastructure, including road and public transportation networks. The projected deficit will be felt most acutely in developing countries, where personal travel is expected to grow several-fold between 2000 and 2050, driven primarily by rising incomes that lead to higher rates of vehicle ownership and greater demand for recreational travel. Freight transport will also increase owing to greater industrialization and globalization, which stimulate regional and international shipment of goods and materials, as well as food trading. The result of increasing transport demand is contributing to an increase in congestion, traffic injuries and fatalities and increasing dependence on petroleum. Furthermore, transport emissions are contributing to climate change and air pollution, especially degradation of air quality in urban areas due to increasing concentrations of fine particulate matter ($PM_{2.5}$) and ozone ($O_3$). Both of these pollutants have an adverse impact on human health. According to the Global Burden of Disease Study 2010, air pollution is responsible annually for 3.2 million deaths from exposure to $PM_{2.5}$ and 0.15 million deaths from exposure to $O_3$; traffic-related injuries contribute 1.4 million fatalities per year.

The transportation sector is a major contributor to global greenhouse gas (GHG) emissions, accounting for around one-quarter (≈7 $GtCO_2$) of present day annual releases, 75% of which come from road transportation. $CO_2$ accounts for the bulk of GHG emissions, with less than 3% for $CH_4$ and $N_2O$ and 5% to 10% for F-gases. Reduction of transportation emissions, which include vehicle lifecycle emissions from use, construction, delivery, dismantling and recycling as well as fuel lifecycle emissions from extraction, preparation and delivery, has proven to be a difficult task. For traditional petroleum-based fuels, tailpipe $CO_2$ emissions typically account for about 80% of the total lifecycle inventory. Emission limits of fine particulate matter ($PM_{2.5}$), CO, VOC and NOx (ozone precursors) are established by emission standards. Exhaust control technology is only part of the solution, though; consumer behaviour and choices also impact the success rate and outcome of public policy efforts to reduce traffic emissions.

World transportation energy use is expected to grow 1.75% annually between 2000 and 2050, with rates two to three times higher in rapidly developing countries (Fig. 1). For Western Europe, the growth in energy demand is expected to be much slower (around 20% to 25% the global rate) because of projected low population growth, improvements in vehicle efficiency, and high fuel taxes. Assuming governments will not implement any new climate policies in the future, transport-related carbon emissions are projected to double by 2050 relative to 2010 levels (Fig. 1). Major reductions could be achieved by switching to public transportation or privately operated minibus jitneys in urban areas and switching to less polluting fuels and technologies, such as advanced biofuels and electric drivetrains. Improving energy efficiency can also deliver carbon reductions. Material substitution and advanced design that lowers airflow drag coefficient could improve light-duty vehicle (LDV) fuel efficiency by 12% to 18%. Another 5% to 20% improvement could be achieved through a variety of vehicle operating efficiencies, such as carpooling, increased vehicle inspections, improved maintenance and better traffic route choice.

Carbon emissions decrease with decreasing fuel carbon content, and for this reason biofuels have been proposed as alternative low carbon fuels to traditional petroleum-based fuels. Issues concerning land competition for food production, for animal grazing and for other uses, and additional carbon releases from land use change (LUC) have, however, raised legitimate concerns about the long-term sustainability of the present generation of biofuels, effects on crop prices, impact on energy security (biofuel feedstocks are often imported from outside Europe) and net effect on lifecycle carbon emissions. LUC values can be large,

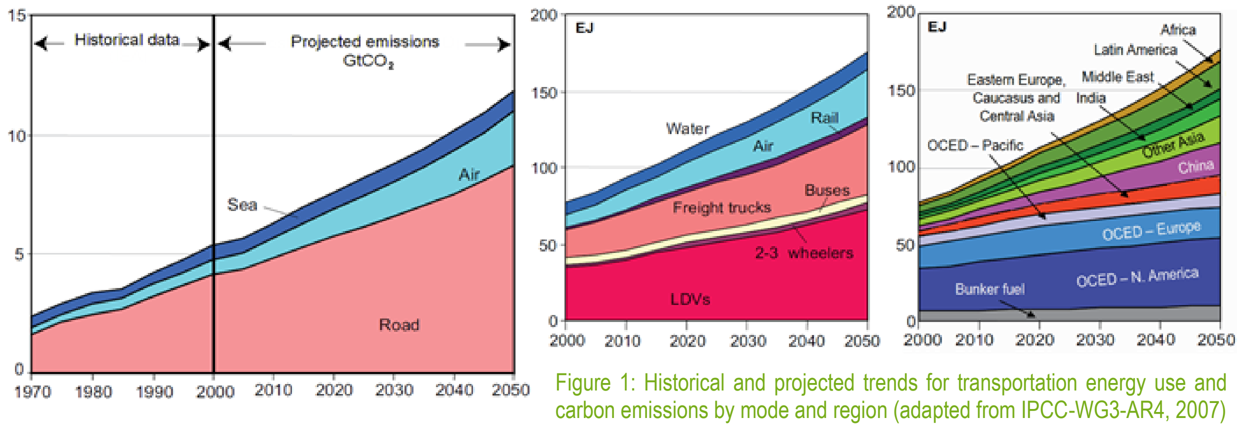


Figure 1: Historical and projected trends for transportation energy use and carbon emissions by mode and region (adapted from IPCC-WG3-AR4, 2007)

increasing $CO_2$ lifecycle emissions by 50% or even more. The potential of biofuels to mitigate carbon emissions depends on feedstock choice and requires a detailed carbon budget analysis, including emissions offset from use of by-products formed during fuel preparation and LUC emissions. Furthermore, vehicles powered by biofuels (and compressed natural gas, CNG) have lower fuel economy. The additional fuel consumption and $CO_2$ emissions partly offset the benefit of using these low carbon content fuels.

Substantial cuts in carbon emissions could be achieved using plug-in hybrids (PHEV[1]), battery electric vehicles (BEV) and hydrogen-based fuel cell vehicles (FCV) that rely on low carbon or decarbonized electricity sources. Renewables, nuclear power and carbon capture and storage (CCS) technology all provide significant opportunities to decarbonize the power sector and improve local air quality by eliminating tailpipe emissions of critical pollutants. However, renewables suffer from supply intermittency; backup generation is likely to come from use of fossil fuels, most probably from combustion of natural gas. High capital costs, potential risks of a severe accident, long-term waste fuel management, and proliferation fears have had a profound impact on social acceptance of nuclear technology. In the aftermath of the Fukushima Daiichi accident, public opinion in Japan, and in several countries in the West, has turned against further use of nuclear energy, whereas other countries have opted for a temporary time out to review national nuclear policies. For this reason, current estimates of 2030 projections of nuclear capacity expansion may be delayed by a decade. Finally, CCS technology is still at the demonstration phase. Only a handful of countries in Europe have addressed CCS in national energy policies that anticipate commercial deployment in new power plant construction sometime in the mid-2020s.

## Case study: Alternative carbon trajectories for the transportation sector

In September 2013, the Intergovernmental Panel on Climate Change (IPCC) released the 1st instalment of the 5th Assessment Report (AR5) titled "*Working Group 1 (WG1): The Physical Science Basis.*" WG1-AR5 has identified transportation as a primary driver of anticipated near-term global temperature rise and as one of the four largest contributing sources to global warming over the next 100 years, along with power generation, industry and biomass burning. Furthermore, concern over population exposure to traffic-related pollutants has grown in response to increasing evidence from epidemiological studies which find that vehicle emissions are linked to both short- and long-term adverse health effects. For these reasons, we present here the results of our own analysis[2] for potential emission reductions and avoided $PM_{2.5}$ health burdens of low carbon measures for road transportation up to 2050.

> *If China and India as well as other Asian countries continue to rapidly industrialize, and if Latin America and Africa fulfill much of their economic potential, transport demand will grow with extreme rapidity over the next several decades. Even in the most conservative economic scenarios though, considerable growth in travel is likely.*
>
> IPCC-WG3-AR4, 2007

The results of our scenarios assessment are presented in Table 1 in terms of aggregate emissions and health impacts over the 40-year period 2011 to 2050, whereas cumulative time trends for $CO_2$ are shown in Fig. 2. In the case of carbon emissions, we also present the reduction in annual emissions for 2050 (end year of the analysis) compared to base year 2010. For particulate matter (PM) emissions, which affect local air quality, we calculate public health impacts, expressed in Disability Adjusted Life Years (DALY[3]). We have considered the effect of modal shift, fuel switch, fuel economy improvement, and change in drive technology. The analysis is for an urban area in Spain with population 360,000 inhabitants (equivalent to the population of the municipality of Bilbao in the Basque Country). In the year 2010 (base year of the analysis), passenger cars travelled 59% of total passenger kilometres (pkm), while buses and metro accounted for 12% and 29%, respectively. Gasoline to Diesel car split is 63% to 37%.

The analysis was carried out using LEAP, an integrated energy planning and climate change mitigation analysis tool developed by the Stockholm Environment Institute. In addition to the [BASE] scenario, 14 alternate pathways have been considered, including 3 different baseload electricity mixes (natural gas, coal, or nuclear). For each fuel mix scenario, different carbon and pollution reduction options were assessed. Results are indicative of the potential outcomes of different strategies that take into account the gradual transformation of current mobility patterns and future infrastructure build-up. A different choice of inputs would certainly yield different

[1] PHEVs are similar to hybrid electric vehicles (HEV) but the battery can also be charged using grid electricity. Plug-in hybrids represent an intermediate (evolutionary) drive technology between HEVs and BEVs.

[2] Complete details are found in Spadaro et al. (2013) BC3 Working Paper Series 2013-14, Basque Centre for Climate Change (BC3), Bilbao, Spain.

[3] DALY is an integrated health impact indicator accounting for disability, illness and life years lost because of premature death.

results, but conclusions would not change. All of the options considered can reduce future emissions but do not address the excess carbon that has already accumulated in the atmosphere in the past, which according to WG1-AR5 may further contribute to climate change and ocean acidification in the coming centuries.

## Case study results

Our results for the electricity mix in [BASE] (72% gas, 18% coal and 10% RES) show that fuel switching, from diesel to CNG or to biodiesel in buses, in conjunction with a 25% modal shift, from passenger cars to public transport, will decrease aggregate carbon emissions by a modest 10%. Absolute emissions, meanwhile, are expected to grow by between 36% and 64% above 2010 levels by 2050. Reducing car demand by half will decrease $CO_2$ aggregate emissions by 17% (Fig. 2), but absolute emissions in 2050 will still be 13% higher than in 2010. Modest reductions (6-12%) are also projected for cumulative particulate emissions, although annual estimates double by 2050. Health impacts, which include premature mortality[4] and health morbidity, are proportional to PM emissions. 95% of health burden is attributed to tailpipe emissions.

According to our analysis, LUC emissions from rapeseed production in scenario [BIO-R, LUC] resulted in higher $CO_2$ aggregate emissions than [BASE]. Fuel substitution from diesel to CNG in buses did not bring any significant carbon savings because of lower bus fuel economy, although the switch did improve local air quality compared to [BASE] scenario. Significant carbon savings can be achieved as indicated in the "aggressive" scenario [BIO-TO, HYB+EV], which assumed 50% reduction in car use, 50% improvement in fleet fuel economy, significant penetration of HEV/BEV drive technologies, and switch to biodiesel use in cars and buses. Emission reductions by 2050 compared to 2010 levels range between 22% for current electricity supply (+6% for PM2.5 vs. factor of 2 for [BASE]) and 49% if fossil fuel generation is equipped with CCS abatement technology. Carbon cumulative emissions decrease by 32% for the current electricity mix and by 42% if CCS technology is employed (Fig. 2).

Table 1: $CO_2$ and $PM_{2.5}$ aggregate emissions and health burdens (2011-2050)

| Scenario | $CO_2$ Emissions 1'000 tonnes | $CO_2$ Emissions 2050† / Base year | $PM_{2.5}$ Emissions and Health burdens: tonnes | $PM_{2.5}$ Emissions and Health burdens: DALY |
|---|---|---|---|---|
| **Baseload electricity mix: 72% Natural Gas (combined cycle, NGCC), 18% Pulverized coal (steam turbine) and 10% Renewables (RES); 25% lower car use by 2050** | | | | |
| Base case [BASE] | 14,930 | +63% ↑ | 1,019 | 3,015 |
| Bus ↪ Diesel to CNG [CNG] | 14,928 | +63% ↑ | 892 | 2,636 |
| Bus ↪ Diesel to Biodiesel (Rapeseed, no LUC) [BIO-R] | 14,138 | +48% ↑ | 960 | 2,871 |
| Bus ↪ Diesel to Biodiesel (Rapeseed, with LUC) [BIO-R, LUC] | 15,020 | +64% ↑ | 960 | 2,871 |
| Bus ↪ Diesel to Biodiesel (Tallow oil) [BIO-TO] | 13,460 | +36% ↑<br>+13% ■ | 945 | 2,819 |
| Car and Bus ↪ Biodiesel (Tallow oil),gasoline HEV/BEV 50% higher fleet fuel economy, 50% lower car demand; plus CCS [BIO-TO, HYB+EV] | 10,108<br>8,601 ◆<br>7,998 □ | –22% ↓<br>–49% ◆<br>–55% □ | 614 | 1,697 |
| **Natural gas baseload electricity (carbon capture & storage, CCS) plus 35% RES; 60% lower car pkm, strong BEV/HEV penetration by 2050, biodiesel buses (tallow oil)** | | | | |
| Car ↪ Bus, Metro (NGCC electricity) | 12,104 | +14% ↑ | 738 | 2,196 |
| Car ↪ Bus, Metro (NGCC & RES electricity) | 10,869 | +3% ↑ | 728 | 2,193 |
| Car ↪ Hybrid, Bus, Metro (NGCC & RES electricity) | 10,353 | –5% ↓ | 590 | 1,715 |
| Car ↪ BEV, Bus, Metro (NGCC & RES electricity); plus CCS | 9,819<br>8,351 ◆ | –12% ↓<br>–44% ◆ | 599 | 1,713 |
| **Coal electricity (condensing plus integrated gasification combined cycle, IGCC); 60% lower car pkm, with significant share of BEV pkm by 2050, biodiesel buses (tallow oil)** | | | | |
| Car ↪ Bus, Metro (Coal electricity) | 16,194 | +41% ↑ | 1,200 | 2,317 |
| Car ↪ Bus, Metro (Coal w/CCS electricity) | 11,678 | –37% ↓ | 998 | 2,264 |
| Car ↪ BEV, Bus, Metro (Coal w/CCS electricity) | 10,659 | –48% ↓ | 901 | 1,831 |
| **Nuclear baseload electricity; 60% lower car demand, plus BEV contribute 40% share of pkm, biodiesel buses (tallow oil)** | | | | |
| Car ↪ Bus, Metro (Nuclear electricity) | 8,562 | –20% ↓ | 728 | 2,193 |
| Car ↪ BEV, Bus, Metro (Nuclear electricity) | 7,219 | –42% ↓ | 599 | 1,838 |

† Percent change in absolute annual emissions: 2050 (end year) vs. 2010 (base year)
◆ Improvement using CCS (77% to 80% lower $CO_2$ lifecycle emissions from power generation)
■ Improvement assuming 50% lower car demand by 2050 (+4% if 60% lower demand)
□ Nuclear-based electricity (replacement of NGCC & coal generation by 2030), plus 10% RES

It is clear from Table 1 that decarbonisation of electricity supply leads to significant $CO_2$ reductions, with nuclear-based electricity scenarios having the lowest aggregate emissions. Switching from fossil fuels to nuclear generation in [BIO-TO, HYB+EV], over the period from 2020 to 2030, reduces carbon aggregate emissions by 46% relative to [BASE], and absolute emissions in 2050 are 55% lower than in 2010 (Fig. 2).

## Carbon prices

Carbon avoidance costs are highly sensitive to assumptions regarding the performance characteristics of the reference vehicle to which alternatives are compared, purchase price of the substitutes, the cost of fuel, vehicle lifetime and kilometres driven, time horizon and social discount rate, and for the case of biofuels, how to account for land use change. The costs shown in Fig. 3 provide key hints into the cost viability of different options for mitigating greenhouse gas emissions in the transportation sector and also permit comparison with opportunity costs from other sectors in the economy. A cost effectiveness assessment is paramount to good policymaking in the framework of sustainable development.

[4] 3,000 DALYs are equivalent to 240 early deaths, or 2,560 life years lost due to shortening of lifetime expectancy.

## Conclusion

To achieve significant carbon emission reductions in the transportation sector by 2050 it will be necessary to reduce the demand for passenger cars, improve vehicle efficiencies, increase share of electric vehicles, and decarbonize electricity supply through the use of renewables, CCS technologies, and/or nuclear energy. Biofuels will also have an important role. The next generation of biofuels (based on cellulosic feedstocks and non-food crops such as algae cultivation) are expected to have much lower carbon lifecycle emissions than current generation biofuels, significantly higher yield rates per land use, and will compete less for croplands.

GHG concentrations are going up at a rate that makes meeting the 450 ppm stabilisation target increasingly difficult. This target is the one that is likely to keep global surface temperature increase within 2ºC from pre-industrial levels, a figure the global community agreed upon in 2009. Because of the long lead times for mitigation measures and the long atmospheric residence time of $CO_2$ (decades to centuries), urgent action is needed to make progress toward the target and one of the most difficult sectors is transportation. Aggressive changes in modes of transportation and fuels for transportation will be needed to make major cuts in emissions of carbon. We believe these are both possible and justifiable, on health grounds as well as climate change grounds. Societies need to take the big steps necessary to make this transition and the time to start is now.


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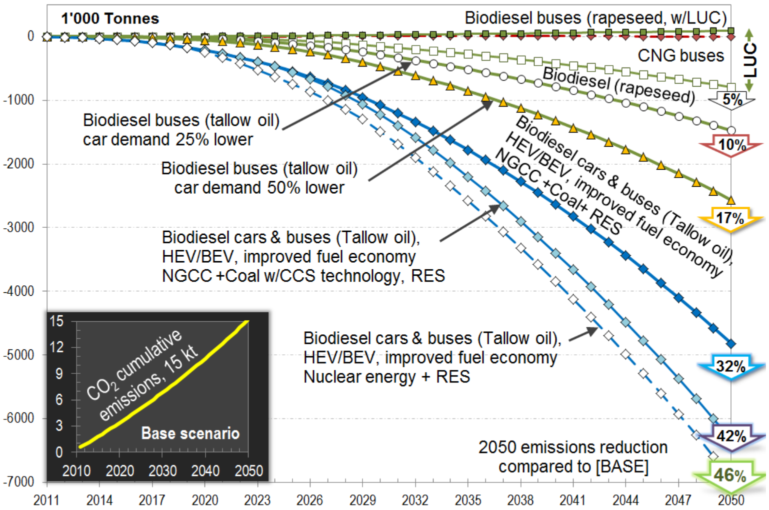


Figure 2: Saved cumulative emissions of $CO_2$ relative to Base scenario.

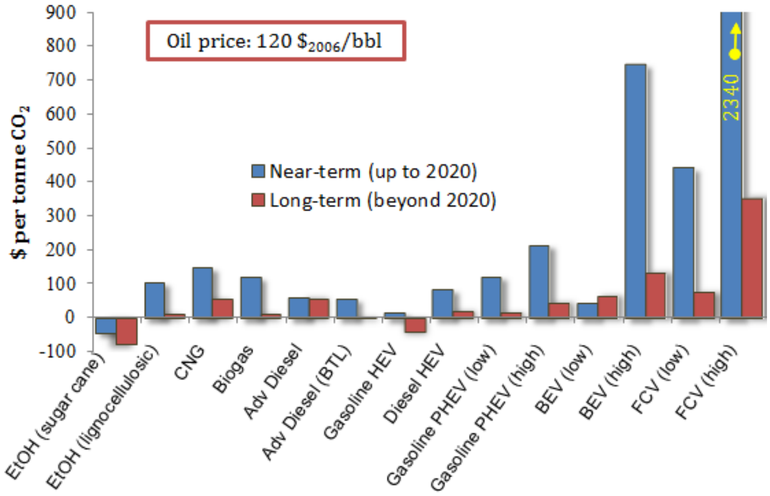


Figure 3: Marginal costs of carbon saved for different vehicle and fuel options compared to a conventional gasoline car. Based on data from IEA (Energy Technology Perspectives, 2010), the 2050 carbon mitigation potential is around 50% of total vehicle emissions at an average $CO_2$ price per tonne of 26 $\$_{2006}$.


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