

## Greenhouse gas emissions and the transport sector

The fact that the transport sector is growing quickly brings advantages, such as quick access to any geographical location on earth, but also disadvantages: noise, congestion and polluting emissions such as carbon dioxide (CO<sub>2</sub>), the greenhouse gas (GHG) primarily responsible for global warming. In the effort to bring GHG emissions under control, improving results in the transport sector is a prime long-term objective. What proportion of CO<sub>2</sub> emissions generated at global and national level are due to the road, air, maritime and rail transport sectors, respectively? What mechanisms can be used to reduce GHG emissions in the transport sector at large?

Despite the Kyoto Protocol and the Bali road map, aimed at reducing greenhouse gas emissions, the situation has not changed: GHG emissions are still rising, year after year. Since the proportion of transport-generated emissions is growing, this sector is a major focus of attention in the effort to curb future GHG emissions.

### Key GHG gases and their sources

- Carbon dioxide (CO<sub>2</sub>) is a gas derived from the combustion of fossil energies, which represents the bulk of anthropic GHG emissions (about 55%). Taken as the reference gas, it has a global warming potential (GWP) of 1.
- Methane (CH<sub>4</sub>) accounts for about 15% of anthropic GHG emissions. Two-thirds of methane emissions result from human activities such as crop farming, the extraction of natural gas and prairie activities (pasture systems and tallgrass burning). The remaining third is of natural origin (fermentation of plant or animal matter). Its impact on climate change is 25 times higher than that of CO<sub>2</sub> and it has a global warming potential (GWP) of 25.
- Nitrogen protoxide (N<sub>2</sub>O), which represents 5% of anthropic GHG emissions, has a GWP 298 times greater than CO<sub>2</sub>. The largest human-related sources of nitrogen protoxide are crop farming (nitrogen fertilizers), biomass combustion and industrial activities.
- Halocarbons and other synthetic fluoro compounds (HFC, PFC and SF<sub>6</sub>) derive mainly from human activities,

for they do not exist in nature. They are used in refrigeration and cooling systems as well as aerosols. These gases account for 15% of GHG emissions and their respective GWP varies very substantially (from 140 to 23,900).

- Nearly 10% of GHG gases result from tropospheric ozone (O<sub>3</sub>), *i.e.* the effect of solar radiation on other atmospheric pollutants, such as nitrogen oxide or carbon monoxide, whose sources include human transport systems.

### Global CO<sub>2</sub> emissions

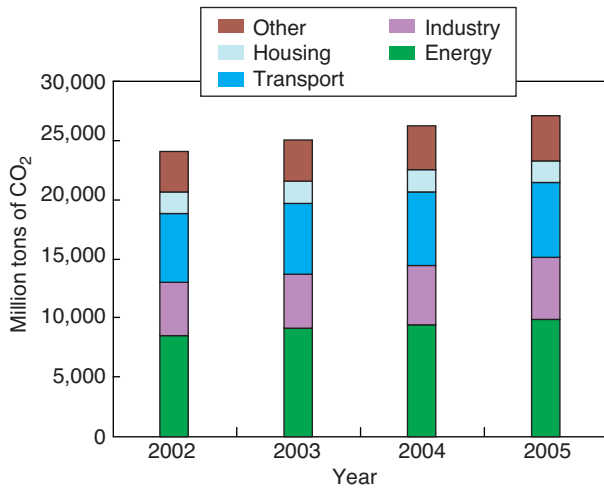
In the last five years, world GHG emissions have grown at an annual rate of 3 to 4%. As for carbon dioxide, the main contributor to the greenhouse effect, emissions totaled 27.1 billion tons (Gt) in 2005.

At global level, transport is the Number Two emitting sector with 7 Gt of carbon dioxide emitted in 2005. It ranks second to energy, which encompasses electricity and heat production (see Figure 1). Forecasts by the International Energy Agency indicate that these emissions will continue to increase; according to the baseline scenario, they will reach 18 Gt by 2050 (source: Energy Technology Perspectives 2008, IEA).

Disparities exist between different parts of the world. The IEA reference scenario shows a steady rise in transport-related CO<sub>2</sub> emissions in developed countries between now and 2050, but exponential growth of same

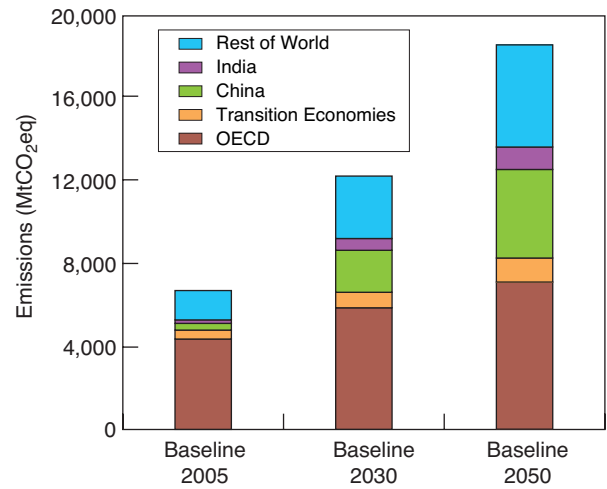
# Greenhouse gas emissions and the transport sector

Fig. 1 - World CO<sub>2</sub> emissions (all sectors)



Source: Based on statistics from the OECD

Fig. 2 - CO<sub>2</sub> emissions due to transport (by region)

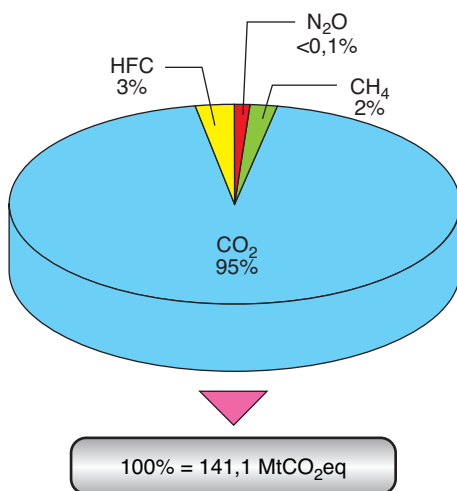


Source: Energy Technology Perspectives 2008, IEA

in developing countries (Figure 2). In particular, China and India are expected to generate 4 Gt and 1.5 Gt respectively by 2050 compared to 0.332 Gt and 0.1 Gt in 2005.

In the wake of efforts by the motor industry to reduce polluting tailpipe emissions, especially NO<sub>x</sub>, the breakdown of transport-related GHG emissions indicates that CO<sub>2</sub> represents by far the largest component of the total. In France in 2006, it stood at 141 MtCO<sub>2</sub>eq and accounted for 95% of all transport-generated GHG emissions (Figure 3). Not surprisingly, one of the main objectives of research today is to lower CO<sub>2</sub> emissions in the transport sector.

Fig. 3 - GHG emissions due to transport in France (2006)



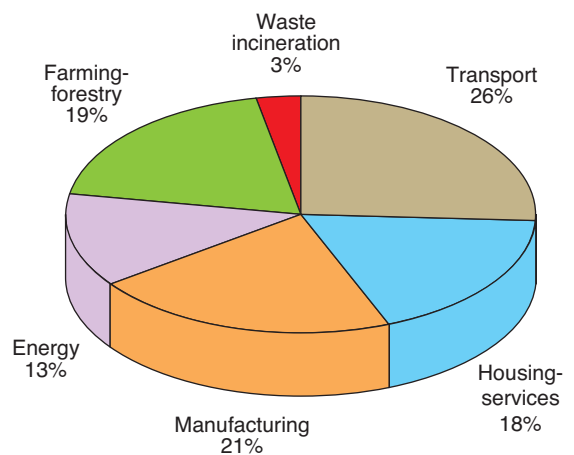
Source: CITEPA

## CO<sub>2</sub> emissions in France

In 2005, the transport sector emitted more CO<sub>2</sub> than any other in France (26% of the total), more than industry, agriculture or housing (Figure 4).

In France, transport CO<sub>2</sub> emissions saw their biggest increase between 1990 and 2005 (+22%), a time when all other sectors except housing were apparently reducing their emissions. The most recent statistics, however, indicate a trend reversal between 2004 and 2005, when the transport sector saw its CO<sub>2</sub> emissions fall by about 1% year-on-year.

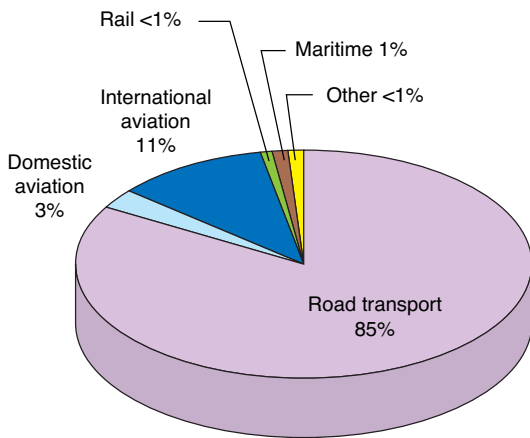
Fig. 4 - CO<sub>2</sub> emissions in France (2005)



Source: CITEPA, February 2007

# Greenhouse gas emissions and the transport sector

Fig. 5 - CO<sub>2</sub> emissions due to transport in France (2005)



Source: Based on statistics from the OECD

## Transport emissions: types and trends

The situation is different for each segment of the transport sector. In France, road transport emits the most CO<sub>2</sub> with 85% of the total; next comes aviation, with a mere 14% (Figure 5). The situation at world level is similar. This explains why the motor industry, in particular, has launched so many R&D projects to reduce automotive CO<sub>2</sub> and why emissions regulations are becoming increasingly stringent.

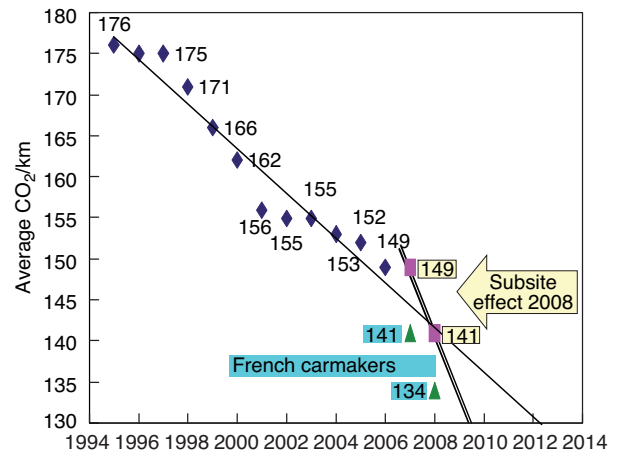
## Road transport

At global level, automotive CO<sub>2</sub> emissions are showing a steady uptrend. In France, they peaked at 140 MtCO<sub>2</sub> in 2002 and have slightly fallen since then.

The regulations apply to local pollutants but not to energy consumption *per se*. The Euro standards are introducing increasingly strict limit values to restrict polluting tailpipe emissions, such as nitrogen oxide and particulates, but they do not cover CO<sub>2</sub> emissions. Up until now, advances in technology have made it possible to meet these standards. On new models, auto manufacturers reduced CO<sub>2</sub> emissions per kilometer traveled. Emissions averaged 200 g in 1990 and less than 140 g of CO<sub>2</sub> in 2008; a passenger car generates its own weight of CO<sub>2</sub> in one year (1,400 kg of CO<sub>2</sub> for 10,000 km/yr). Another reason for progress: government subsidies to help households purchase automobiles that pollute less and get better fuel efficiency (Figure 6).

But further efforts are required. The "Grenelle de l'Environnement" round table set a target of 130 g/km by 2020 for the French fleet, whose 2008 emissions averaged 165 g/km. This target is very ambitious, especially considering that it takes a fleet about 13 years to turn

Fig. 6 - Average CO<sub>2</sub> emissions for new auto models



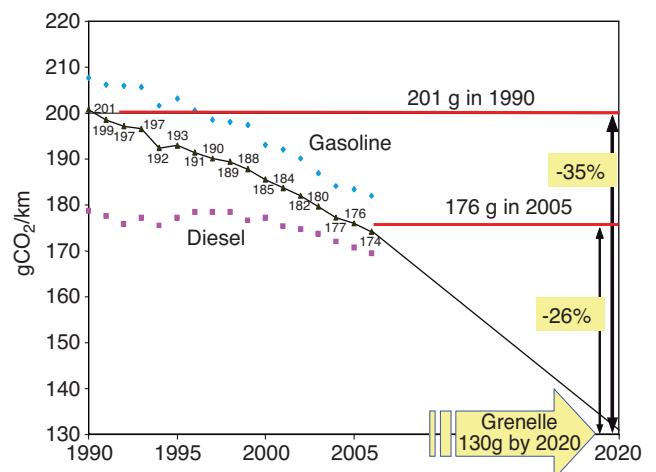
Source: Trade association of French automakers (CCFA)

over and that the older vehicles on the road offer far lower environmental efficiency and performance levels compared to more recent models (Figure 7).

The next stage is under discussion at European level. Two-thirds of all new models are expected to reach the 2012 target of 130 g/km via the improvement of engine technology. Further technical improvements, such as the use of better tires or biofuels, may also be required to lower emissions by an additional 10 g/km (to 120 g/km).

Strides forward in technology may suffice to curb the growth of CO<sub>2</sub> emissions in developed countries, where the size of existing motor fleets is stagnating or rising slowly. However, technical innovations in automotive propulsion systems will not offset the increase in fleet size. World automotive CO<sub>2</sub> emissions should rise by between 1.5 and 3% a year.

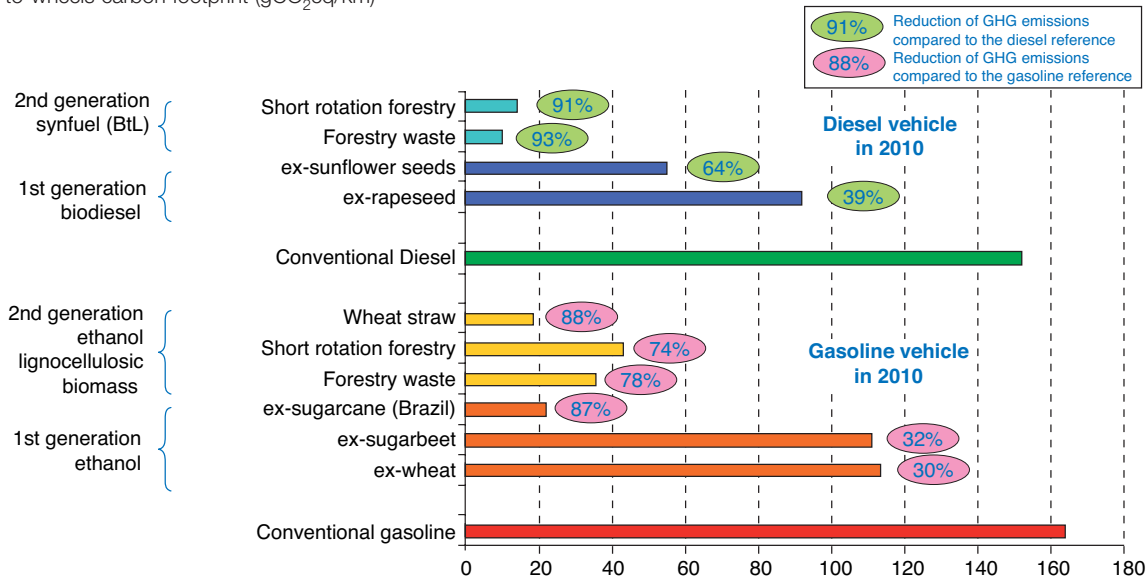
Fig. 7 - Average CO<sub>2</sub> emissions for the French motor fleet and targets by the "Grenelle de l'Environnement" round table.



Source: Trade association of French automakers (CCFA)

## Greenhouse gas emissions and the transport sector

Fig. 8 - Well-to-wheels carbon footprint (gCO<sub>2</sub>eq/km)



Source: Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, Version 2c, JRC/Eucar/Concawe study, March 2007

Refineries are also involved in the battle against polluting emissions. Motor fuel specifications, especially as regards sulfur content, have become increasingly stiff. This makes industrial processes more complex and also increases the carbon footprint at the refinery.

The improvement of existing vehicles and conventional motor fuels is one way to bring down automotive CO<sub>2</sub> emissions, but there are others as well:

- the use of hybrid vehicles yields immediate consumption gains and lowers the quantity of CO<sub>2</sub> emitted per kilometer,
- the use of alternative motor fuels instead of conventional petroleum-based fuels can decrease total GHG emissions (CO<sub>2</sub> equivalent, as well as methane and N<sub>2</sub>O) all along the chain of motor fuel production and use.

The methods used to evaluate emissions reductions for these pathways need to be improved. However, several studies have indicated net gains, especially for biofuel pathways. According to a 2007 well-to-wheels study carried out by JRC/Eucar/Concawe, biofuels may reduce GHG emissions by between 30% and more than 90% compared to gasoline and diesel, depending on the pathways and resources examined.

Finally, one must consider the last link in the chain: the driver. There is plenty of room for improving driving behavior, although motorists have recently been more interested in eco-driving because it can save fuel. Certain types of behavior—driving too fast, over-accelerating only to slam on the brakes, and frequent gear-changing—can boost consumption by 20% on the highway and 40% in the city (source: The OECD Observer). Driving with the

engine in overspeed and without changing gears can increase vehicle consumption by about 30%. The European Climate Change Program estimated in 2001 that a reduction of 50 MtCO<sub>2</sub> a year could be achieved if member states (at the time, the EU of Fifteen) imposed eco-driving.

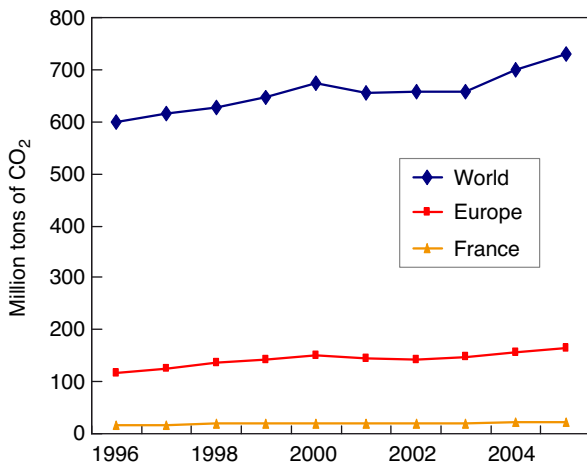
### Air transport

Technological progress has been made in the fight to reduce GHG emissions, but this cannot compensate for the growth of world air traffic (+50% passengers-km in the last ten years). Since 1990, CO<sub>2</sub> emissions directly tied to jet fuel consumption have seen an 87% increase and are likely to continue to rise, undermining efforts being made in other industrial sectors to comply with 1997 Kyoto commitments. According to the baseline scenarios of the Committee on Aviation Environmental Protection, world air transport emissions are expected to exceed one billion tons by 2020.

Currently, air transport emissions are not within the purview of the Kyoto Protocol. Nevertheless, the European Commission decided to include the aviation sector in the EU Emissions Trading Scheme (EU ETS), followed by a European Parliament vote of approval on July 8, 2008. The GHG emissions of intra-community flights as well as planes departing or landing in the EU will be included, effective 2012. This will apply to all airlines, irrespective of nationality, which will then be allowed to sell pollution credits on the EU carbon market or buy credits if their emissions increase.

## Greenhouse gas emissions and the transport sector

Fig. 9 - CO<sub>2</sub> emissions due to air transport



Source: Based on statistics from the IEA

Given this regulatory context and considering the capital investment on R&D required in order to bring low-CO<sub>2</sub> jet fuel to market, the airlines and the aircraft manufacturers will have to evaluate the price per ton of CO<sub>2</sub> avoided for various types of fuel (e.g. biofuels, alternative fuels and other sources) from 2012 on.

Are there any solutions for air transport? Switching from a liquid fuel to some other type seems much harder – virtually impossible – for planes than automobiles. The storage volume required per energy unit is a disadvantage for alternative solutions such as hydrogen, which means that kerosene should remain unchallenged in the foreseeable future. For this sector, producing a synfuel ex-biomass to airline specifications—for instance, using a BtL pathway (Fischer-Tropsch process)—would be a major step forward.

For airlines, jet fuel is a major expense item, especially in recent years with the surge in oil price. Companies are concentrating on reducing fuel consumption, hence CO<sub>2</sub> emissions, by:

- optimizing fuel consumption (by minimizing on-board mass, maximizing efficient use of the cruising speed and improving engine maintenance procedures),
- replacing planes in existing fleets with more recent, fuel-efficient models.

Broader companion measures are also called for, to ensure optimized air traffic, more airport runways (fewer approach maneuvers) and shorter taxiways.

France aims to reduce jet fuel consumption and CO<sub>2</sub> emissions per passenger-km by 50% between now and 2020.

### Rail transport

In France, most of the trunk lines have already been electrified, but regional lines have lagged behind. Today, more than 50% of the rail system in France is electrified. Most of the rail traffic runs along certain key corridors, so electricity represents three-quarters of the energy consumed by the rail sector.

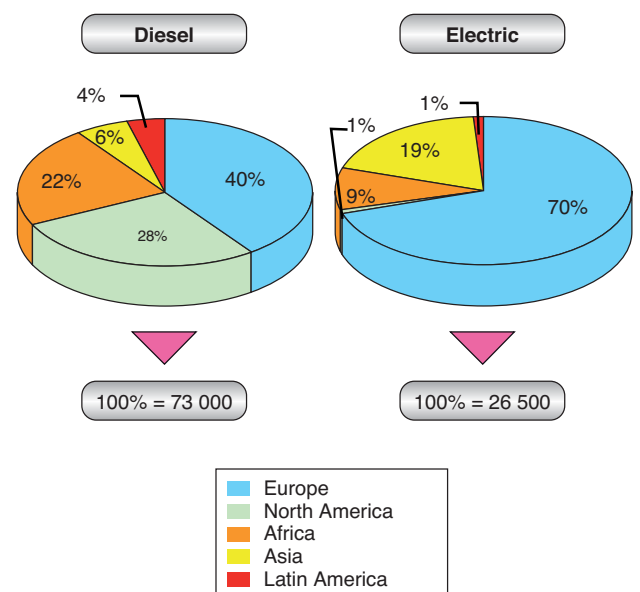
In the next few years, electrification on secondary lines is expected to continue until all rail infrastructure in France has been electrified. The "Grenelle de l'Environnement" round table forecast that only trains equipped with electric propulsion systems would run after 2016.

France is one of the countries that has made the most progress in the electrification of its rail infrastructure, but the situation is quite different in other parts of the world: China has electrified about 20% of its rail infrastructure, and the United States and Canada less than 1%. In 2000, there were three times more diesel locomotives than electric motor units in the world (especially outside Europe).

Rail transport is also important as an alternative to the road sector, especially for freight. It diverts traffic away from the road system and improves environmental performance. Many projects involving combined transport techniques and rail highways are under consideration.

For a more comprehensive assessment, one would have to consider the source of the electricity used to power the rail system as well as its carbon footprint. Although the latter is fairly good in France, it is not so good in

Fig. 10 - World locomotive fleet in 2000, by propulsion system and region



Source : Based on data from the World Bank Railway Data Base

## Greenhouse gas emissions and the transport sector

other European countries where the electricity is produced at gas- or coal-fired power plants without CO<sub>2</sub> capture and storage.

### Maritime transport

In volume terms, 90% of the world's freight is shipped by sea. Maritime transport emits less carbon per kilometer and per ton carried than rail, road or air transport. Even so, according to one IEA estimate, the sector (mostly cargo ships) generates 543 million tons of CO<sub>2</sub> a year, and the estimates by the International Maritime Organization are twice as high.

After doubling between 1985 and 2007, maritime shipping is expected to triple at least between now and 2020, with a major impact on CO<sub>2</sub> emissions. During the same period, container ship traffic should increase by a factor of six. The power ratings of container ships (hence their emissions levels) are among the highest for seagoing vessels.

Traveling at a slower speed would decrease consumption, but this goes counter not only to recent trends—ships now travel at 25 knots versus 21 in the 1990s—but also to the current rationale in favor of shorter journey times and more frequent runs.

The improvement of ships is a second possible source of consumption gains. Hulls can be improved to attain better penetration through water and new types of propeller can be developed to maximize engine power.

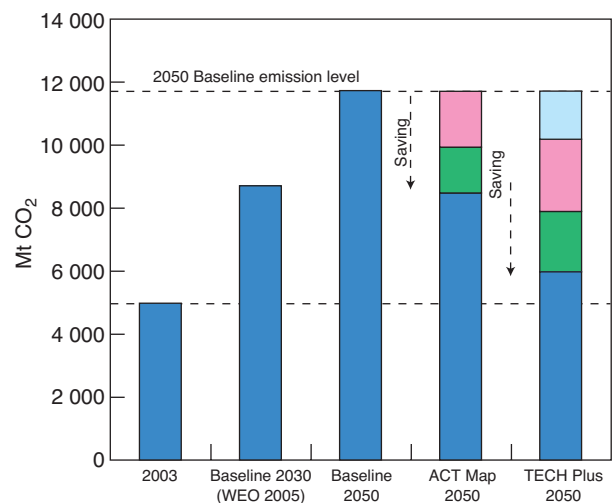
As for ship propulsion systems, it is thought that fuel cells will not be ready for a few decades, except for a few particular applications (coastal and inland waterway freight shipping) and also that new biofuel applications may emerge. However, a few technical problems remain to be solved before the degree of reliability required in maritime transport can be ensured.

### Conclusion

There is much to be done to reduce CO<sub>2</sub> emissions in the transport sector. If no action is taken, they will reach an estimated 18 billion tons by 2050, driven primarily by road transport and by growth in developing countries, whose automobile fleets are increasing in size at a spectacular rate.

One IEA scenario assumes that decisive action is taken: it caps CO<sub>2</sub> emissions at 10 Gt in 2050, or 28% below the baseline IEA Act Map scenario. Potential reductions are achieved by improvements in vehicle energy efficiency

Fig. 11 - IEA scenarios - CO<sub>2</sub> emissions for the transport sector



Source : International Energy Agency

and the use of biofuels (two-thirds and one-third, respectively). To realize this scenario, there would have to be real change in policy in all countries, including investment policy (especially relative to R&D).

As we can see, it is crucial to encourage market penetration of fuel-efficient, low-emissions vehicles and pursue R&D to improve existing technologies and develop alternatives for the future. Furthermore, individual drivers must do their share by adopting the most efficient driving behavior to reduce fuel consumption, hence CO<sub>2</sub> emissions.

In the area of rail transport, the electrification of infrastructure may yield most of the hoped-for progress, at least as far as transport itself is concerned. However, the centralization of CO<sub>2</sub> emissions or nuclear waste at electricity production facilities must be taken into consideration. In maritime transport, expected to grow in future, new technologies (hull types, propulsion systems, and perhaps fuels) and new methods of navigation will probably be implemented to minimize energy expenditure.

The air transport situation is even more complex, with no revolutionary technology yet on the medium-term horizon. If alternative jet fuels are eventually developed, their biggest contribution will relate to potential gains in consumption and energy efficiency.

Simon Vinot & Paula Coussy  
 simon.vinot@ifp.fr - paula.coussy@ifp.fr  
 Final draft submitted in December 2008