Road transport efficiency

In brief

Most passenger vehicles still rely on conventional petrol or diesel engines, for which incremental improvements can be foreseen in terms of energy efficiency. Electric motors offer higher efficiency, either as Battery electrical vehicles (BEVs), which are purely electrical, Hybrid electrical vehicles (HEVs), which combine an internal combustion engine with an electric motor, or Plug-in hybrid electrical vehicles (PHEVs), where electricity can be charged from the grid. The main challenge is the low energy density of available batteries, which limits the range between charges.

> "Transport accounts for 32 % of European energy consumption and 28 % of total CO_2 emissions. However the sector is expected to account for some 90 % of the increase in emissions between 1990 and 2010 and could become the primary reason for the EU missing its Kyoto target. For example passenger transport on European roads is forecast to increase by 19 % while freight haulage on the roads is set to increase by 50 %. This massive rise has renewed research efforts to find new vehicle technologies that will reduce or eliminate CO_2 emitted by the various transport segments."
>
> European Commission

The technology

At present, the reciprocating internal combustion engine (ICE), either as homogeneous charge spark ignition (petrol engines) or stratified charge compression ignition (diesel engines), dominates the drive trains of road vehicles. Most new improvements to the petrol engine reduce the drivability (acceleration times) of vehicles, while 'lean burn direct injection petrol engines' prevent the use of 3-way catalyst emissions control and increase vehicle cost. Current turbo-charged diesel engines using the 'common rail' injection system already offer 20 % fuel savings over petrol engines.

Electric motors offer a much higher efficiency than ICEs. Battery electrical vehicles (BEV) are purely electrical, using rechargeable batteries. They produce no exhaust emissions. The Hybrid electrical vehicle (HEV) combines an ICE and an electrical motor. Like the BEV, it recuperates energy used in braking to recharge the battery. In a 'series' HEV, the ICE is used to charge an on-board battery or supply electrical power directly to the electrical motor, which drives the wheel and the accessories. In a 'parallel' HEV, both the ICE and the electrical motor can propel the vehicle, or they can be used simultaneously for maximum power, with a potential fuel saving in a smooth driving style in an urban environment is of 30 to 40 %. Plug-in hybrid vehicles (PHEV) load electricity from the grid or through onboard electricity generation using ICE or even fuel cells. The deployment of BEVs and PHEVs can also benefit from the decarbonisation of the electricity generation mix in Europe.

Ongoing research

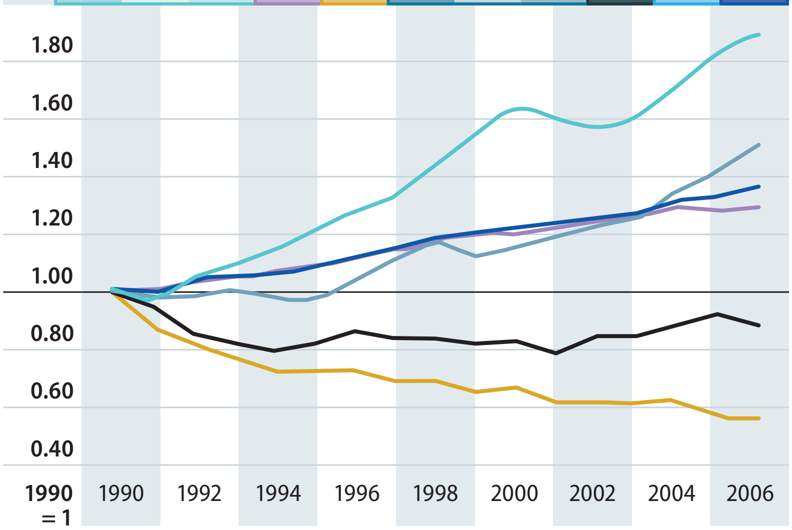
For the ICE, incremental improvements can be foreseen by technical development of the current state-of-the-art technology. One such development is the Homogeneous Charge Compression Ignition (HCCI) engine, where combustion takes place spontaneously and homogeneously without flame propagation in the combustion chamber, sharing the gain in efficiency of the diesel engine and the low emissions of the petrol engine.

Fact file

- In 2006, the transport sector consumed 31.4 % of the total final energy consumption (of which 81.9 % is road transport) and was responsible for roughly 28 % of the total CO_2 emissions (EU-27).
- In 2007, road transport constituted about 83.1 % of total transport demand in passenger transport and 45.6 % in freight transport (EU-27).
- Road transport accounts for 71 % of transport-related CO_2 emissions and passenger cars constitute 63 % of this.
- In 2007, there were 229.8 million passenger vehicles in the EU-27 and new vehicle sales were 15.96 million vehicles in that year.
- The average emission from new (conventional) cars registered in the EU-25 in 2007 amounted to 158 gCO_2/km TtW (tank-to-wheel), which is a 15.1 % improvement compared to 1995.
- Direct CO_2 emissions from road transportation amounted to 902 Mt CO_2 in the EU-27 in 2006 and energy consumption was 300.4 Mtoe. Due to an increasing transport demand, it is expected that transport related energy consumption will rise to more than 350 Mtoe by 2030 despite efficiency improvements through vehicle technology and alternative fuels.

GHG emissions from transport – EU-27 in 2006 (million tonnes CO_2 equivalent)

	TOTAL CIVIL AVIATION	Civil Aviation (domestic)	International Bunkers – Aviation	ROAD TRANSPORTATION	RAILWAYS	TOTAL NAVIGATION	Navigation (domestic)	International Bunkers – Marine	OTHER TRANSPORTATION	TOTAL TRANSPORT	TOTAL EMISSIONS
1990	83.2	17.0	66.2	714.9	14.7	131.0	20.9	110.1	11.7	955.4	5 748.3
1991	81.7	16.4	65.4	723.5	13.0	129.2	21.4	107.8	11.1	958.5	5 644.2
1992	87.4	16.8	70.5	748.9	12.1	129.6	20.3	109.2	9.9	987.9	5 460.2
1993	91.3	16.6	74.7	759.2	11.4	132.6	20.9	111.7	9.5	1 004.0	5 376.2
1994	95.1	16.4	78.7	766.7	10.7	129.0	20.4	108.6	9.3	1 010.9	5 347.5
1995	100.7	17.7	83.0	781.8	10.6	128.9	19.0	109.9	9.6	1 031.7	5 407.0
1996	106.5	19.3	87.3	805.2	10.7	136.6	19.6	117.0	10.2	1 069.1	5 523.7
1997	111.3	20.3	91.1	816.0	10.2	147.0	19.6	127.4	9.8	1 094.4	5 434.0
1998	119.5	21.4	98.1	843.1	10.1	153.7	20.4	133.3	9.9	1 136.2	5 398.0
1999	128.4	23.0	105.4	860.1	9.7	147.2	20.5	126.7	9.6	1 154.9	5 290.3
2000	135.9	24.1	111.8	861.3	9.8	151.6	18.8	132.7	9.6	1 168.1	5 309.8
2001	133.0	23.4	109.6	877.1	9.1	157.2	19.2	138.0	9.2	1 185.6	5 368.8
2002	130.7	22.7	108.0	890.7	9.1	161.4	18.8	142.5	9.9	1 201.8	5 330.5
2003	134.6	22.9	111.7	899.7	9.1	165.1	20.9	144.2	9.9	1 218.4	5 435.7
2004	142.8	23.8	118.9	919.0	9.1	177.0	21.3	155.7	10.3	1 258.2	5 465.7
2005	151.6	25.6	126.0	917.5	8.4	185.4	21.9	163.5	10.8	1 273.5	5 446.2
2006	157.1	25.9	131.2	924.2	8.3	197.4	23.6	173.8	10.3	1 297.3	5 447.8



Source: European Environment Agency (EEA)

For BEV and HEV, reducing the cost, weight and size of the batteries is the greatest technology challenge. A possible improvement for HEV is the use of diesel, rather than petrol ICE to further gain in fuel-to-energy efficiency. Both BEV and PHEV, provide zero emission ranges. For PHEV, this would be somewhere between 20 and 60 km, while for the BEV, of the order, to be viable, well above 100 km.

Further efficiency gains can be made to all vehicles with ICT in vehicles and in road infrastructure as well as improved aerodynamics, lightweight materials and tyre design.

The European Green Cars initiative is one of the three Public Private Partnerships (PPPs) included in the Commission's economic recovery package. The budget envelope for this initiative is EUR 5 billion to boost the automotive industry in a time of economic hardship, and support the development of new, sustainable forms of road transport. Of this, EUR 4 billion will be made available through loans by the European Investment Bank (EIB), and EUR 1 billion through support to research, with equal contribution from the Seventh Framework Programme for Research (FP7) and from the private sector.

The industry

Many of the above listed technologies that focus on improvements of the internal combustion engine and reduction of the vehicle road load will have to be implemented to meet the 2012 - 2015 specific CO_2 targets for passenger cars [Regulation (EC) No 443/2009]. This will lead to a CO_2 emission avoidance of roughly 70 Mt CO_2 in 2020. The 95 g CO_2 target for 2020, as laid down in EC 443/2009, will additionally require the mass market roll-out of more advanced technologies such as strong hybrids, electrical vehicles and hydrogen fuel cell vehicles. The current BEV and PHEV market share in the EU is very low. While this is also true for Asia and the USA, hybrid shares are already much higher in Japan and the US versus Europe, mainly because of the very low share of diesel vehicles in these passenger car markets.

Barriers

For battery vehicles, the prime challenge is the low-energy density of available batteries, which limits the range of driving between charges. The lack of robust high power and high energy battery systems for mobile applications is a major bottleneck: lead-acid batteries are cheap (ca. EUR 100 per kWh), too heavy (low energy and power density) and lack deep cycling capability, while other battery technologies, although they can double the vehicle's driving autonomy and last longer than lead-acid batteries, are still too expensive (NiMh or Li-Ion, ca. 500 – 1500 €/kWh). On the other hand, the widespread use of BEVs and PHEVs will be delayed unless social and infrastructural barriers are addressed in addition to technological development. Standardised electric infrastructures, e.g. recharging points, will need to be provided.

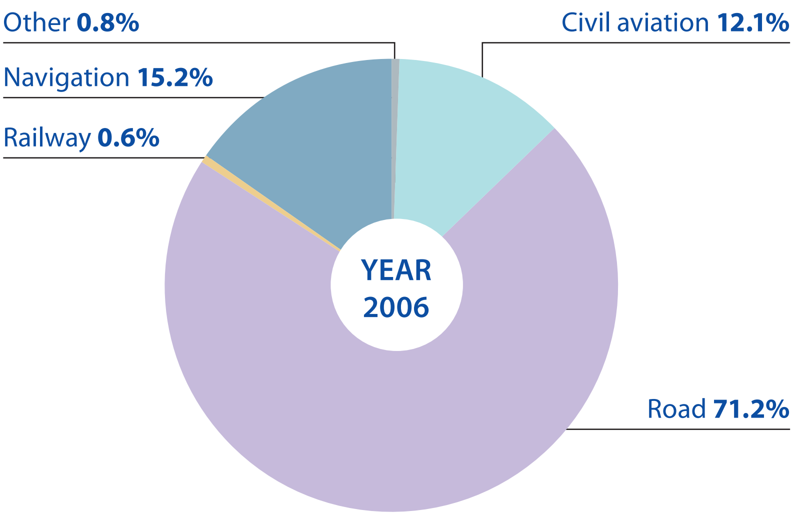
Needs

The challenge to develop an electrified road transportation system depends upon strong research programmes to develop suitable basic technologies together with the appropriate system integration, in particular.

Storage systems: On-board storage of electricity is the main challenge. The batteries need to increase their energy density, safety and lifetime, while reducing their cost, as

GHG emissions from transport – EU-27 in 2006 by mode (shares %)

	TOTAL CIVIL AVIATION	Civil Aviation (domestic)	International Bunkers – Aviation	ROAD TRANSPORTATION	RAILWAYS	TOTAL NAVIGATION	Navigation (domestic)	International Bunkers – Marine	OTHER TRANSPORTATION	TOTAL TRANSPORT	TOTAL EMISSIONS
1990	8.7	20.4	79.6	74.8	1.5	13.7	16.0	84.0	1.2	16.6	100
1991	8.5	20.0	80.0	75.5	1.4	13.5	16.5	83.5	1.2	17.0	100
1992	8.8	19.2	80.8	75.8	1.2	13.1	15.7	84.3	1.0	18.1	100
1993	9.1	18.2	81.8	75.6	1.1	13.2	15.7	84.3	0.9	18.7	100
1994	9.4	17.2	82.8	75.8	1.1	12.8	15.8	84.2	0.9	18.9	100
1995	9.8	17.6	82.4	75.8	1.0	12.5	14.8	85.2	0.9	19.1	100
1996	10.0	18.1	81.9	75.3	1.0	12.8	14.4	85.6	1.0	19.4	100
1997	10.2	18.2	81.8	74.6	0.9	13.4	13.3	86.7	0.9	20.1	100
1998	10.5	17.9	82.1	74.2	0.9	13.5	13.3	86.7	0.9	21.0	100
1999	11.1	17.9	82.1	74.5	0.8	12.7	13.9	86.1	0.8	21.8	100
2000	11.6	17.7	82.3	73.7	0.8	13.0	12.4	87.6	0.8	22.0	100
2001	11.2	17.6	82.4	74.0	0.8	13.3	12.2	87.8	0.8	22.1	100
2002	10.9	17.4	82.6	74.1	0.8	13.4	11.7	88.3	0.8	22.5	100
2003	11.0	17.0	83.0	73.8	0.7	13.6	12.7	87.3	0.8	22.4	100
2004	11.3	16.7	83.3	73.0	0.7	14.1	12.0	88.0	0.8	23.0	100
2005	11.9	16.9	83.1	72.0	0.7	14.6	11.8	88.2	0.8	23.4	100
2006	12.1	16.5	83.5	71.2	0.6	15.2	12.0	88.0	0.8	23.8	100



Source: European Environment Agency (EEA) well as the recharging time. Today's battery research is focused on high power technology mainly oriented to HEV, while for BEV and PHEV high energy batteries are required. The target is to reach high energy density batteries above 200 Wh/kg. With the use of alternative electrochemical components, safety of the cell is critical and in particular, to avoid possible thermal runaway. Therefore, it is important to develop safe high energy systems. All these requirements need further understanding of the electrochemistry, in order to extend the lifetime of the batteries.

Electric motor (EM): The main challenge for EM is possibly its coexistence with combustion engines in HEVs, the same is applicable to the power electronics. Therefore, an increase in EM performance (power and torque) with a reduction of its volume and weight is required. In addition, the EM needs to operate in a harsh environment and care is needed to reduce losses and increase their efficiency per volume. This might be met by developing new materials, magnets and insulation material or even with new EM concepts.

System architecture: The main research need is the integration of the power-train system to minimise cost and optimise efficiency. This also includes research in power electronics components, addressing thermal system management, as well as high frequency switching components. Key points, relating to the storage systems, is the development of reliable battery charging and discharging algorithms, including monitoring and switching (on/off) of individual cells.

Concerning the ICE in HEVs, managing its efficiency by considering the traffic situation needs to be addressed. ICE downsizing, high pressure supercharging and simplification and integration of the control electronics are important topics to be considered.

Infrastructure: Vehicle-to-grid (V2G) adds functionality to the EVs. A V2G system needs to be aware of the user's charging needs and the state of the grid. Therefore, the development of basic control algorithms and hardware, user's acceptance and a new business model as interface, needs to be considered at an earlier stage. Other enablers in the integration of EV are the on-board charging and metering devices and their connection to the grid by V2G interfaces. Finally, the capability to provide charging points on streets will strongly support an early acceptance of EVs.

Demonstration and field tests: Demonstration and field tests need to be conducted in order to generate know-how with respect to daily usage and customer feedback of PHEVs and BEVs. The above R&D measures will be able to address some of the barriers for the electrification of the road transportation system. They might need to be complemented by additional market stimulus measures in order to reach a market deployment of BEVs and PHEVs in Europe.

For further information:

SETIS section on road transport efficiency
http://setis.ec.europa.eu/technologies/RoadTransport

Transport Research Knowledge Centre
http://www.transport-research.info

Fact file

Anticipated CO_2 savings

- For ICE-driven vehicles, a combination of new technologies could lead to approximately 20 % vehicle CO_2 reduction versus today's petrol vehicles. With CO_2 emissions of approximately 450 g CO_2 per kWh electricity (net) in the EU mix and a demand of roughly 15 – 20 kWh per 100 km, the use of BEVs could lead to 68 – 90 g WtW CO_2 emissions per km versus roughly 180 g WtW CO_2 emissions per km of the currently available new vehicle fleet (that corresponds to the 158 g TtW emissions of the new vehicle fleet).

Technology objectives and actions for R&D	
• Efficient Internal Combustion Engine (ICE) Vehicles and Advanced Fuels	New ICE designs including advanced fuel injection and downsizing, • New combustion concepts, perhaps assisted by new fuels, which offer the potential to combine high efficiency and low emissions, • Improved components including batteries, control systems, lightweight materials and low friction lubricants which will support new combustion concepts, • Advanced bio fuels which offer higher Greenhouse Gas (GHG) savings versus today's 1st generation biofuels.
• Hybrids and Intelligent Energy Management Systems which use the energy produced by the engine more efficiently	Development of simplified designs that reduce cost, • Improvements to batteries, materials, auxiliaries, electric motors and vehicle energy management systems to optimise fuel consumption in real-life operating conditions, • Intelligent systems that reduce energy use through driver assistance and improved traffic management.
• Fuel Cell Vehicles & Low-Carbon/H_2 Fuels (impact on the market expected only after 2020)	High temperature membranes, bipolar plates, air systems and humidity management, • Hydrogen storage, improve cost and performance of fuel cell systems, • Development of cost-effective low-carbon routes for production of hydrogen and distribution infrastructures.