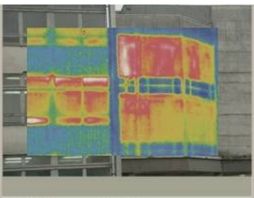

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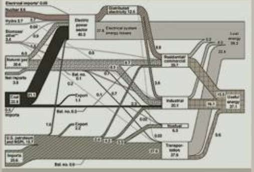

Study on Clean Transport Systems

Project 2010 n. 419-1-Unit Move B4

Multiple Framework Services Contract with reopened competition for Technical Assistance TREN/R1/350-2008-Lot3-COWI

Final Report

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Executive summary

The Roadmap for moving to a competitive low carbon economy in 2050[1] showed that transport-related emissions of GHG should be reduced by around 60% by 2050 compared to 1990 in order to achieve a reduction of GHG emissions that is consistent with the long-term requirements for limiting climate change to 2 °C. In March 2011 the European Commission adopted the White Paper - Roadmap to a Single European Transport Area [2], which proposes a series of policy measures to achieve the 60% GHG emissions reduction goal.

The Clean Transport System study explores possible contributions of various fuel-technology combinations in the transport sector to the 60% greenhouse gas (GHG) emissions reduction goal of the White Paper - Roadmap to a Single European Transport Area. However, other objectives set by the White Paper (e.g. limiting the growth of congestion) were not within the scope of the current study. Measures related to the internalisation of external costs, internal market measures, other taxation measures (i.e. VAT on international passenger transport services; vehicle taxation; company car taxation) and measures related to transport planning are not evaluated in the current study.

The Reference projection quantified within the CTS study demonstrates that continuation of trends which only involve conventional fuels and technologies cannot deliver the required emission reduction despite improvements in vehicle efficiencies expected also under current trends. Alternative fuel and technologies have to develop and penetrate the transportation markets in order to meet the emission target.

The future choices and market development of the different alternative fuel-technology combinations will have to be compatible with the emissions cut objective in the transport sector but also with similar objectives applied for the overall energy system. The study takes place in the overall context of the EU's emission reduction targets of 80-95% compared to 1990 and therefore assumes that electricity generation and hydrogen production will be almost fully decarbonised by 2050.

It is expected that the alternative fuel-technology combinations will undergo substantial cost-efficiency improvement in the future, as a result of RTD efforts and anticipation of large-scale market penetration. However, the extent of the progress is highly uncertain and depends on policy choices. Thus, the possible contribution of fuel-technology combinations was quantified under different scenario assumptions for technology-cost performance, infrastructure and regulatory framework in the transport sector. The three main scenario-storylines developed are:

- Dominant electricity storyline; with two variants one with strong competitive advantage of vehicle technologies based on batteries and one with great improvement in costs and performance of fuel cell technologies

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[1] COM(2011) 112

[2] COM(2011) 144

- Dominant biomass storyline; success with production and market diffusion of new generation biofuels
- "Renew" storyline, a combination of elements of the previous two scenario-storylines, with again two variants, one with higher success in battery driven vehicles and one with higher success in fuel cells.

Further, each scenario-case was analysed under two alternative regulatory options: tank-to-wheel CO_2 standards and tank-to-wheel energy efficiency standards.

The scenario quantification was performed using the PRIMES-TREMOVE transport model developed by E3Mlab of National Technical University of Athens (NTUA) which allows studying causality effects between policy measures and consumer choices, and implied transformations and changes deemed appropriate within the logic of each scenario. The scenarios are dynamic projections of the transport sector for each EU Member State to the horizon of 2050. The PRIMES-TREMOVE Transport model operates in linkage mode with the entire PRIMES model which provides consistent projections of energy demand, supply and emissions, including interactions with production of biofuels.

The PRIMES TREMOVE transport model is a sophisticated modelling tool featuring a detailed representation of the transport sector, particularly road transport. Through the interactions of the PRIMES TREMOVE transport model with the overall PRIMES energy system model and the PRIMES biomass supply model the case results are embedded in the overall energy system context and are not independent from the interactions with the rest of the energy system. The analysis provided with this study therefore assesses the implications of different assumptions related to techno-economic developments of technologies and policy measures in terms of final and primary energy demand, emissions –both tank-to-wheel and well-to-wheel- and costs analysis. The analysis takes into account limits given by the PRIMES biomass supply model and the overall development of the energy system, in particular the power generation system and the refineries as provided by the PRIMES energy system model. Further with the interaction of the PROMETHEUS world energy model, changes in resource availabilities were also taken into account and their impact on the European transport system analysed.

The scenario quantification has shown that achieving the goal set out in the White Paper, of reducing emissions by around 60% compared to 1990 levels, is possible with different alternative fuel-technology combinations. The different combinations lead to different structures of the vehicle stock, different final and primary energy demand structures, as well as costs. Two storylines focus on "one-main paradigm" solutions i.e. electro-mobility and biofuels, whereas the third story-line assumes the parallel development of various paradigms. The "one-main paradigm" scenarios focusing mainly on one energy carrier and/or powertrain technology are highly dependent on the development of the related technology. The third scenario-storyline assuming the parallel development does not rely as much on one technology but leads to higher costs.

The model projections reveal that grid connected passenger cars, both plug-in hybrids and battery electric vehicles, would significantly penetrate the market and be used in all scenario-cases quantified, albeit at different degrees; even in the dominant biomass scenarios where the progress in techno-economic performance of battery based vehicles was assumed to be the most limited, the stock of plug-in hybrids (in particular small and medium sized) represents 37.4% of total vehicle stock by 2050 under CO_2 standards. The results of the dominant electricity scenarios also project that grid connected vehicles would represent a high share of the stock even under the assumption that fuel cell vehicles become market competitive; under the assumption that only the techno-economic performance of battery based vehicles improve, grid connected vehicles would represent 74.1% of the passenger car and LDV vehicle stock in 2050. Under the assumption that the techno-economic performance of fuel cell based vehicles greatly develops, grid connected vehicles would still represent 45% of the passenger car and LDV vehicle share in 2050, more than the fuel cell based vehicles, which will represent 38.3% of the stock in 2050[3].

Behind the strong market penetration of electric vehicles is the assumption of a strong improvement of battery electric vehicles both in terms of battery costs and in terms of range, allowed by reductions in battery weight. The issues of vehicle range and the density of refuelling/recharging infrastructure are handled explicitly in the PRIMES TREMOVE model: the model represents a proxy of the heterogeneity of trips in terms of length and purpose, and associates utility penalties to any mismatch between vehicle range or refuelling density and trip length, which influences consumer choices. The model is thus able to simulate the relation between vehicle ranges and trip lengths, allowing for differentiation in technology diffusion by transportation market segment. Assumptions about strong development of range capabilities of battery-based vehicles by 2050 allowing electric vehicles to cover ranges between 350 and 500km play an important role driving high market penetration of grid-based electromobility in the context of the dominant electricity scenario. The more limited penetration of vehicles in the dominant biomass scenario is due to both higher costs and reduced ranges of vehicles.

Although the model includes fuel cell hydrogen vehicles in all cases, the degree of techno-economic development assumed varies significantly, as the technology prospects are at present surrounded by high degree of uncertainty. The model projections reveal that with the substantial learning rates of approx. 6% p.a. between 2011 and 2050 and very steep decrease in costs before 2020, as reflected in the technology assumptions in the fuel cell success case, fuel cells can achieve large market shares in passenger car and LDV vehicle stock reaching 38% in 2050. With the learning rate at half this level and more evenly distributed over time, fuel cells are not likely to manage achieving the necessary techno-economic development for large scale market penetration: they are projected to get a share in passenger car and LDV vehicle stock of 11.4% in 2050 in the battery success case.

The CTS scenario designs assume success stories regarding the timely development of infrastructure or electro-mobility (charging infrastructure and hydrogen distribution). The model-based projections were designed so as the infrastructure develops prior to demand development without obstructing this development. Market failure cases were not studied within this project.

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[3] The “Fuel Cell Success” case, where great improvement in costs and performance of fuel cell technology take place, has only been analysed as additional to the "Battery Success" case. In other words, no case was modelled where fuel cell vehicles are successful while battery-electric vehicles are not.

Table ES1: Share of electro-mobility in road passenger transportation (% in pkm)

		2020	2030	2050
Dominant electricity with battery success	**grid-based***	3%	26%	63%
	H2-based	0%	2%	12%
Dominant electricity with fuel cell success	grid-based*	3%	23%	51%
	H2-based	0%	18%	39%
RENEW scenario with battery success	**grid-based***	4%	26%	61%
	H2-based	0%	2%	10%
RENEW scenario with fuel cell success	grid-based*	4%	24%	50%
	H2-based	2%	16%	33%
Dominant biomass scenario	**grid-based***	3%	11%	24%
	H2-based	0%	1%	4%

* including the electric activity of PHEV

Table ES2: Share of electro-mobility in road freight transportation[4] (% in tkm)

		2020	2030	2050
Dominant electricity with battery success	**grid-based**	0%	4%	17%
	H2-based	0%	0%	3%
Dominant electricity with fuel cell success	grid-based	0%	4%	15%
	H2-based	0%	2%	10%
RENEW scenario with battery success	**grid-based**	0%	2%	6%
	H2-based	0%	0%	2%
RENEW scenario with fuel cell success	grid-based	0%	2%	6%
	H2-based	0%	1%	8%
Dominant biomass scenario	**grid-based**	0%	1%	3%
	H2-based	0%	0%	2%

The cumulative sales see a strong increase in the sales of alternative vehicles beyond 2030 where their sales increase substantially. Until 2020 cumulative sales of conventional vehicles still represent the majority, but there is competition from the hybrid vehicles. Beyond 2020 new sales of conventional vehicles decrease steadily, implying low additional cumulative sales. Plug-in hybrids start penetrating the market between 2020 and 2030, by which year they reach cumulative sales between 50 and 61 million depending on the scenario. Between 2030 and 2050, the sales of electric and fuel cell vehicles penetrate the market, particularly in the electro-mobility success cases; cumulative sales of electric vehicles in the battery success case reach 225million, and fuel cells are projected to reach 221 million cumulative sales.

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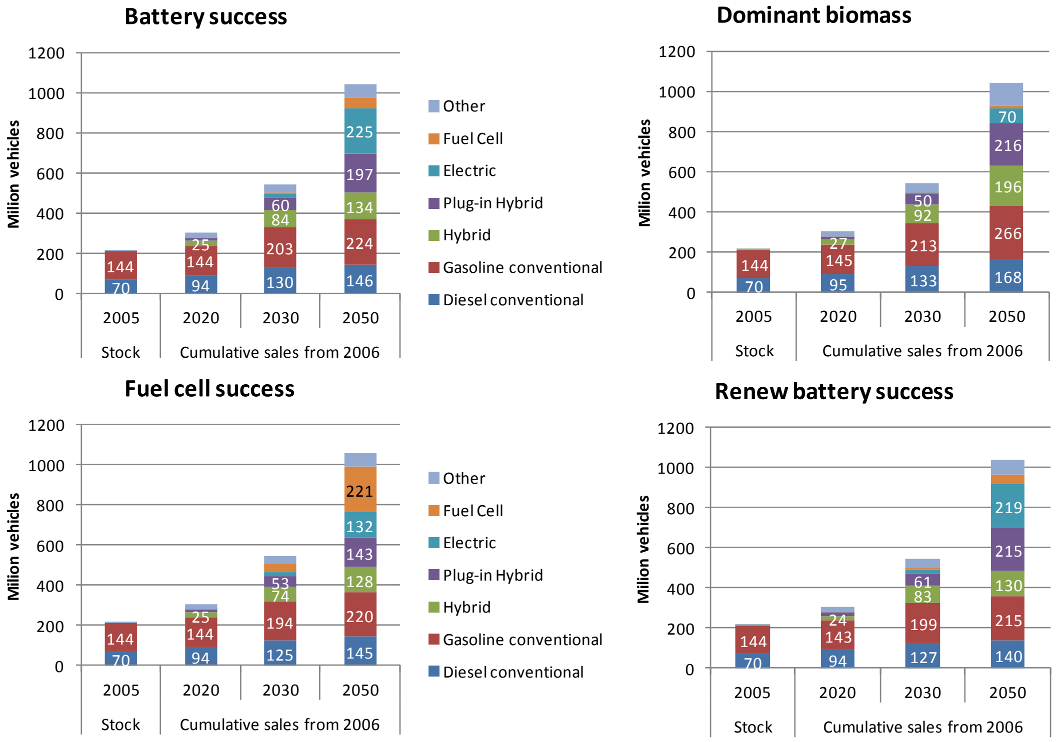
[4] Includes both HDVs and LDVs for freight transportation

Figure ES1: Cumulative sales of passenger cars and LDVs in million vehicles



A common feature of all the cases analysed within the study is the presence of biofuels (incl. bio-methane). The energy system projection, based on the PRIMES model, assumes that in the context of the decarbonisation scenarios (80% lower emissions in 2050 from 1990 levels) biomass supply develops towards second generation feedstock types and technologies. While respecting strict sustainability criteria regarding land use and lifecycle emissions, the technology and productivity progress is assumed to allow relatively large production of bio-energy commodities in the EU. Despite increasing prices of biomass commodities, as projected by PRIMES, the economic simulation suggests that they will penetrate the markets under the assumptions of decarbonisation scenarios up to a certain volume level limited by resource and import constraints and sustainability considerations.

Thus the amount of biofuels used in the transport sector rises continuously throughout the scenario projections, reaching high shares in final energy demand even in scenarios with high electro-mobility. The increase in biofuels is projected to take place also in the non-road transport sector, where few alternative fuels other than the use of biofuels are available to reduce emissions[5]. For non-road transport the increase in biofuels takes place almost entirely after 2030, where the penetration of second generation biofuels into the market is projected. The shares of biofuels in non-road transport rise thereafter achieving between 32% of total final non-road energy demand in the dominant electricity and 39% in the dominant biomass. For road transport the shares of biofuels also increase over time, however the increase in

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[5] While for freight maritime transport using LNG exists as an option in the model, but the drivers (infrastructure, logistics) assumed are not sufficient to allow this technology to penetrate the market, LNG for HDVs is not considered for the purposes of this study.

absolute values is small in the scenarios which see a strong increase of electro-mobility. The amounts of biomass used in the dominant biomass scenario are considerable; an analysis of their availability was conducted with the PRIMES biomass supply model. The results of the latter indicate that such a level of biofuel production implies almost exhaustion of land possibilities in the EU, according to strict criteria about sustainable land use and no interference with other land uses for food and forestry; the scenario also involves significant increase in biofuel and feedstock imports.

Table ES3: Final energy demand for biofuels in the transport sector for the main quantified cases

(Mtoe)		2020	2030	2050	***share of biofuels in final energy demand (2050)***
Reference		**30**	**36**	**38**	**10%**
Dom. Elec. Battery success	**Total**	**29**	**37**	**61**	**28%**
	Road	*29*	*36*	*35*	*25%*
	Non Road	*0*	*0*	*26*	*32%*
Dom. Biomass	**Total**	**29**	**45**	**112**	**44%**
	Road	*29*	*45*	*81*	*47%*
	Non Road	*0*	*1*	*31*	*39%*
Renew Battery success	**Total**	**29**	**37**	**73**	**32%**
	Road	*29*	*36*	*45*	*30%*
	Non Road	*0*	*1*	*28*	*35%*

For gaseous fuels, mainly methane (including both natural gas and biogas) and LPG, the model projections show a differentiation between the mid and the long-term. For the mid-term, gaseous fuels present an economically attractive option to reduce emissions at a certain extent, through a technology which is mature today. Assuming timely development of refuelling infrastructure at an adequate density for gaseous fuel vehicles and harmonisation of fuel distribution standards across Europe, the dominant biomass case projects the highest market penetration: 12.8% of the total car and LDV stock in the midterm (2030-2035) are projected to run on gaseous fuels. In the long-term, however, the emission reduction objectives become stricter and in this context the gaseous fuels are less attractive than other options; consequently, the share of gaseous vehicles decreases in the long term in all quantified cases which are forced to obtain the 60% emission reduction target. In the dominant biomass scenario which has the “weakest” possibilities regarding electro-mobility, the share of gaseous fuels is the highest in 2050 among all scenarios; in the dominant electricity with battery success case the share of gaseous powered vehicles is the smallest in 2050 among all scenarios, reducing almost to the 2005 level.

The development of conventional ICE technologies in terms of efficiency gains for all road transport modes in all the cases quantified is important and goes beyond the improvements assumed in the Reference scenario: Reference scenario efficiency gains were in the range of 0.9% p.a. from 2010 to 2050, they are between 1.1% p.a. in the dominant electricity and 1.4% in the dominant biomass case for which the strongest efficiency improvements are assumed to take place as electro-mobility options are “weak”; for this case the improvements, in particular the improvements for road freight transport are a fundamental contribution to the achievement of the mitigation target. The higher efficiency of the vehicles allows a more efficient use of resources, which in particular when using a limited resource such as biomass, should also be considered as an important target.

Table ES 4: Efficiency improvements for selected technologies (average annual rate of change from 2010)

	Average ICE cars	Average ICE HDVs
Reference	0.85%	0.60%
Battery success	0.95%	1.05%
Fuel cell success	0.95%	1.05%
Dominant Biomass	1.30%	1.43%
Renew battery success	0.95%	1.05%

From a policy perspective the cases studied were quantified assuming either a CO_2 regulation or energy efficiency standards.

CO_2 regulation is a policy instrument, currently in place, which force manufacturers to limit the average emissions of the new vehicles sold. The CO_2 standards facilitate the transition towards vehicles running on energy carriers with few or no tailpipe emissions. Moderate CO_2 standards of around 100gCO_2/km facilitate the market uptake of gaseous fuelled vehicles; lower CO_2 standards favour the market penetration first of plug-in hybrids and even lower ones of vehicles without tailpipe emissions such as battery electric or fuel cell vehicles. The CO_2 standards for cars are assumed to reach in the dominant electricity cases about 20gCO_2/km in 2050. The CO_2 standards in the dominant biomass scenario are set at higher levels, as the target can be achieved through higher use of biofuels; requiring high strictness in the CO_2 standard would not be appropriate since the electro-mobility technologies are developing at a low pace in the dominant biomass scenario.

Variations of the quantified cases with energy efficiency standards (instead of CO_2 standards) were also carried out. Such standards imply imposition of energy efficiency standards to the onboard energy conversion processes; the standards apply on the average new fleet. In the dominant electricity with battery success scenarios the replacement of strong CO_2 standards by strong energy efficiency standards strengthens slightly the further penetration of battery electric vehicles, which have a very high on board efficiency. In the fuel cell success case the situation is different: strong energy efficiency standards as those imposed in the battery success case lead to a strong reduction in the market penetration of fuel cells as the onboard efficiency of fuel cell is inherently lower than battery electric vehicles due to the further transformation process which occurs on board –hydrogen to electricity through the fuel cell. The replacement of CO_2 standards by energy efficiency standards also penalises the market penetration of gaseous vehicles; whereas in terms of emissions these vehicles perform better than gasoline or diesel ICEs, in terms of onboard efficiency they are slightly worse, therefore reducing their competitive advantage. In the dominant biomass case the energy efficiency standards allow for slightly easier penetration of more efficient hybrid vehicles, which are penalised with CO_2 standards due to their remaining tailpipe emissions. In the dominant biomass context, energy efficiency standards allow for a slight shift towards technologies that use biomass more efficiently.

The policy choice regarding the different standards (CO_2 or efficiency or mixed) has substantial consequences facilitating the penetration of specific vehicle types while penalising others; the only vehicle type not penalised in either case are battery electric vehicles.

The assumed techno-economic progress of batteries and fuel cells is projected not to be sufficient for these technologies to penetrate massively into freight and public road transport. The technical limitations posed by the additional weight of batteries and the limitations due to the costs of batteries in the sizes needed for large vehicles imply that large market penetration outside of specific market segments e.g. urban areas and dedicated fleets, is limited. In the dominant electricity with battery success case urban and short distance trips of freight and public road transport do become electrified; electric and fuel cell vehicles achieve a share of approx. 22% in the vehicle stock of trucks and buses by 2050. In the fuel cell success case where also the techno-economic characteristics of fuel cells improve considerably, the penetration of both electric vehicles in the short and urban trips can be observed, with additionally the penetration of fuel cell vehicles, increasing the share of fuel cell and electric vehicles to almost 27% by 2050. In the fuel cell success cases, electro-mobility fuelled by hydrogen develops also in the long distance market segments both for passenger and freight as the range limitations of fuel cell vehicles are not so strong as to limit penetration in these distance classes; this is demonstrated by the fact that fuel cell vehicles and electric vehicles both penetrate the market in the fuel cell success case. In case of development of fuel cell and battery electric vehicles the two technologies are observed to co-exist in different market segments. In the dominant biomass case where the progress of batteries and fuel cells was assumed not to be as strong, the share of these technologies in freight and public road transport is projected to be limited.

All scenarios see a strong development in the efficiencies of conventional ICE technologies and hybrids for trucks and buses, in particular in the dominant biomass case where these improvements are crucial in contributing to the achievement of the 60% target. The big shift therefore in the heavy duty and bus transport modes is a shift towards hybrid vehicles which allow for increased energy efficiency compared to conventional ICEs. The share of hybrid buses and trucks increases most in the dominant biomass case where the penetration of battery electric and fuel cell vehicles is limited: the share of hybrids in the stock of trucks and buses is of almost 48% by 2050 in this case. In the dominant electricity cases the share of hybrids in the stock of trucks and buses is lower at around 40%, as they are complemented by battery electric and fuel cell vehicles which penetrate the market and achieve a share of almost 27% in the stock of trucks and buses. In all scenarios the share of hybrid vehicles exceeds the share of conventional ICEs by 2050.

The non-road transportation is included in the projections towards emission reduction and its contribution depends on economic and technical possibilities. These possibilities are mainly implementing additional energy efficiency measures and using biofuels; thus restructuring is less radical than in road transport. As fuel cells and batteries are assumed not to play any role in non-road transport modes, the variations between the different cases quantified are very limited.

The model projections reveal that biofuels penetrate all non-road transport modes; the quantity of biofuels used in non-road transport modes remains constant between the scenarios. Railways are assumed to be almost fully electrified by 2050; the remaining diesel used is blended with biodiesel therefore further reducing the small remaining emissions from railways. Some modal shift towards rail both in passenger and freight transportation is projected in all cases quantified, driven by the relative increase in costs of private road transportation and aviation[6].

For aviation the improvements in terms of emission reductions and energy efficiency are driven by a combination of technical and non-technical energy efficiency measures as well as substantial introduction of bio-kerosene as a transportation fuel. The majority of the energy efficiency potential assumed for aviation is projected to be cost-effective already in the Reference scenario context; therefore further energy efficiency in the cases quantified in the study are limited. The big change compared to the Reference scenario which allows large amounts of emission reduction, is the assumption of the availability and subsequent penetration of bio-kerosene in aviation. The use of bio-kerosene allows for further substantial emission reductions in aviation.

Inland navigation, for which the model does not have a very detailed description, changes only limitedly. Although slight energy efficiency gains are projected, emission reductions take place mainly due to the penetration of biofuels –bio-heavy and biodiesel (BtL)- in the sector. Freight maritime transport using LNG exists as an option in the model, but the drivers (infrastructure, logistics) assumed in this scenario are not sufficient to allow this technology to penetrate the market.

Final energy demand in all the cases analysed decreases substantially compared to the Reference scenario- between 35% in the dominant biomass case and 43% in the dominant electricity with battery success case. The decrease is caused by the substantial energy efficiency improvements in ICE and a shift towards hybrids in freight and public road transport as well as shifts in technologies and fuels mainly in passenger road transport. The changes in non-road transport are mainly a shift towards fungible biofuels which reduce emissions but do not allow for significant efficiency gains.

The highest reduction in final energy demand is in the battery success scenario where the technology with the highest efficiency is used: the battery electric vehicle. The scenario with the least reduction, but nonetheless a very substantial one compared to 2005, is the dominant biomass case which uses less efficient technologies compared to battery electric vehicles.

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[6] The impact on rail transport activity is rather limited because measures related to the internalisation of external costs, internal market measures and other taxation measures are not considered in this study.

Table ES5: Final energy demand for the transport sector

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Reference	362	398	392	387	30	24
Battery success	362	371	325	220	-37	-142
Dominant Biomass	362	372	332	251	-31	-111
Renew battery success	362	369	324	228	-38	-134

All scenarios see a substantial reduction of the use of mineral oil products in final energy demand, which reduce by around 60% in all the scenarios. This reduction is mainly due to a shift towards other energy carriers and technologies in road passenger transport and is mainly due to a substantial penetration of biofuels in freight road transport and non-road transportation modes; rail transport represents the exception in non-road transport as it is assumed to be almost fully electrified by 2050. The results show that the emission reduction objective drives significant change towards lower dependence on mineral oil.

Table ES6: Evolution of final energy demand for mineral oil

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Reference	352	359	346	339	-7	-14
Battery success	352	328	261	108	-91	-244
Dominant Biomass	352	329	264	104	-89	-249
Renew battery success	352	326	260	106	-93	-246

Total biomass demand increases substantially in all scenarios analysed, increasing by between 60%, in the dominant electricity and almost 200% in the dominant biomass from Reference scenario levels. The maximum biomass consumption (112Mtoe in the dominant biomass case) has been estimated by the biomass supply model as a level of biofuel production which implies almost exhaustion of land possibilities in the EU, according to strict criteria about sustainable land use and no interference with other land uses for food and forestry; further it also implies significant increase in biofuel and feedstock imports.

The total demand for natural gas at its maximum reaches 11Mtoe in 2030; this amount represents a large increase compared to the Reference scenario. Nonetheless compared to the total natural gas final energy demand as projected by the PRIMES decarbonisation scenario used as context scenario for this study it only represents 5% of the total consumption.

In all the scenarios analysed within this study the model projects a strong increase in direct electricity consumption in the transport sector due to at least partial electrification of road transport. The highest increase in electricity demand is in the dominant electricity scenarios with battery success. The additional electricity required by the transport sector, additional to the stationary uses[7], in the battery success case is 421TWh in 2050 or an additional 14.3% above other stationary uses of electricity in that year.

Table ES7: Final energy demand for electricity in a PRIMES decarbonisation scenario and the transport electricity demand from the transport scenarios

(TWh)	2005	2030	2050
Electricity demand in stationary uses	2688	3181	2944
Final electricity demand in transport			
Dominant electricity battery success	74	187	421
incremental electricity demand(*)		*5.9%*	*14.3%*
Dominant biomass		149	272
incremental electricity demand(*)		*5%*	*9%*
Renew battery success		184	376
incremental electricity demand(*)		*6%*	*13%*

(*) above other uses (stationary) of electricity

It is assumed within the overall PRIMES model that the charging of batteries will take place mainly during base load hours, as a result of development of smart metering and the application of price-based incentives with electricity tariffs varying by time of use. In this way the charging of batteries will have a load profile which will exert a positive effect on power generation by smoothing the overall load curve; the smooth load curve is beneficial for the cost of electricity and for the development of capital intensive power plant technologies, as those that enable decarbonisation in the power sector (RES, CCS and nuclear), since it allows for better use of large base load devices and reduces the necessity for peak devices. Simulations assuming failure in inciting base load charging of vehicles show large adverse effects on the electricity system in terms of costs and reliability. Using vehicle batteries as storage devices was not studied in depth; preliminary analysis suggests that this would be non economic to the extent that the storage would deviate from base load charging. The system simulations have assumed hydrogen production from electrolysis and transportation and distribution of hydrogen through dedicated infrastructure. Hydrogen production from electrolysis provides opportunities for indirect storage of variable RES.

The total additional demand for electricity in the scenarios with hydrogen is substantially higher than the battery cases: the dominant electricity with fuel cell success scenario has an overall electricity demand (including indirect electricity use from electrolysis) which is 76% higher than the dominant electricity battery success scenario. The increased demand for electricity from the transport sector including hydrogen production therefore corresponds to an incremental demand of 25.2% additional to the stationary uses. The possibility to produce hydrogen at all times leads to a more efficient use of base load power plants, which leads to further benefits from a cost perspective for the power sector which partly compensates for the additional costs of hydrogen production.

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[7] Stationary uses include final energy demand of electricity from industry, households and the tertiary sector.

Table ES8: Final energy demand for electricity in a PRIMES decarbonisation scenario and the transport electricity demand from the transport scenarios incl. electricity necessary for hydrogen production

(TWh)	2005	2030	2050
Final energy demand for electricity excl. transport	2688	3181	2944
Transport electricity demand (incl. indirect demand for hydrogen production)			
Dominant electricity fuel cell success	74	311	742
incremental electricity demand(*)		*9.8%*	*25.2%*
Dominant biomass		154	326
incremental electricity demand(*)		*5%*	*11%*
Renew fuel cell success		271	651
incremental electricity demand(*)		*9%*	*22%*

(*) above other uses (stationary) of electricity

The electricity and hydrogen prices as used in the PRIMES-TREMOVE model come from the overall PRIMES model; the prices are taken from a scenario with an overall emission reduction objective of 80% lower GHG emissions compared to 1990. The electrification of transportation is beneficial for electricity prices because of the smoothing of the load curve, resulting from charging at base load time.

Overall emissions trajectories follow similar pathways between the cases analysed, following the trajectory determined in the Low carbon energy Roadmap published by the European Commission in March 2011 and in the White Paper on transport also published in March 2011. The emissions decrease steadily from 2015 onwards; all cases quantified achieve the 60% emission reduction target, established for the transportation sector. The cumulative emissions nonetheless show different results between the scenarios; the fuel cell success scenario sees the lowest emissions due to the assumption of early techno-economic improvement of fuel cell vehicles in this scenario. The dominant biomass scenario sees the highest cumulative emissions due to the slower emission reductions over time.

Table ES9: CO_2 emissions

	Changes in TTW emissions compared to 2005 *(index 1990=100)*			**Cumulative CO_2 emissions 2011-2050** *($MtCO_2$)*	
	2020	**2030**	**2050**	**TTW**	**WTW**
Reference	1.32	1.27	1.25	41813	46480
Battery success	1.22	0.98	0.41	30099	37092
Fuel cell success	1.21	0.94	0.41	29641	36734
Dominant Biomass	1.22	0.99	0.40	30605	37503
Renew battery success	1.21	0.98	0.41	29973	36872

Emissions of pollutants NO_X, SO_2, and PM decrease substantially in the cases analysed. Externalities assumed within the course of this study relate to air pollution, congestion, accidents and noise. Although externalities are partially accounted for in the taxation, in the choice of vehicles the consumer does not see costs related to externalities; these can nonetheless be considered to influence choice indirectly through the policies included in the scenarios. The costs related to externalities decrease in all the cases quantified compared to the Reference scenario. Externalities related to air pollution decrease by over 90% in urban areas in all scenarios. There are also reductions in the external costs related to noise for scenarios with electro-mobility. Externalities related to congestion and accidents do not change significantly between the cases quantified and the Reference scenario because the activity for the different transport modes remains at similar levels.

The quantified cases see a strong shift towards CAPEX (capital expenditure as opposed to OPEX, the expenditures corresponding to variable costs), as vehicle purchase costs increase and corresponding fuel expenditures decrease. Independently of the actual cost of the scenario, a shift towards higher CAPEX is an issue per se as it implies that individuals will have to ensure more access to capital financing. The model-based analysis has not captured the consequences of this issue, as it has applied to representative consumers; in reality, as the heterogeneity of consumers and income classes is high, the shift towards higher CAPEX will imply additional costs and certainly higher barriers to the choice of high capital costs vehicles, than those modelled. Policy instruments and private sector actions will have to be in place to address this issue; an example is the case of leasing deals from manufacturers for the batteries. The issue of financing large scale infrastructure developments necessary for the successful deployment of new technologies such as battery electric or fuel cell vehicles is of different nature, since in these cases the distribution business usually operates under a regulated monopoly regime. However, policy issues arise because of the need to anticipate market developments and regulate investment in infrastructure prior to the actual market development.

The cheapest case is the fuel cell success case; these low costs are driven by the assumed cost reduction in fuel cell technology. The most expensive scenarios are the “renew” cases in which the simultaneous development of all transport options was assumed which therefore do not develop as much in terms of techno-economic performance as in the “one-paradigm” cases. The strong emission reductions coupled with the strong reduction in use of oil products leads to a substantial reduction in the bill for imported fuels which decreases approx. 55% below 2005 levels in all scenarios quantified by 2050.

A further sensitivity analysis was undertaken with a variant assuming no development of electro-mobility and large availability of natural gas worldwide (as a result of development of shale gas), therefore allowing the synthetic fuel GTL to penetrate the market and be imported in the EU.

The world energy model Prometheus was used to quantify a world energy scenario with higher availability of gas to determine production of GTL globally assuming that similar transport policies develop worldwide in a context of global climate mitigation action. From 2030 onwards oil and coal consumption in this scenario decreases compares to a standard decarbonisation, without large scale availability of GTL; lower oil consumption is due to lower direct consumption in transport and lower coal consumption is due to lower electricity demand in transport. Gas consumption increases due mainly to the use of GTL in transport. The shift in the use of fossil fuels nonetheless does little to change the distribution of gas primary production among the main producers; the largest proportion of the increase in gas production occurs in the CIS region where the GTL boom worldwide also facilitates CIS resources (conventional or shale) reaching remote and virtually inaccessible world markets in the form of gas derived liquid fuels. The North American region is already assumed to produce a large portion of its gas from shale gas in the standard decarbonisation scenario; the increases in the BTL-GTL scenario therefore are relatively modest but still sufficient to maintain virtual gas self-sufficiency in the region despite the large increase in gas requirements for the transport sector. The MENA region which in the standard decarbonisation scenario becomes the dominant player in gas international trade also sees a significant increase in volumes of gas produced, GTL production affording a cheaper and more flexible way of marketing gas in remote parts of the planet. Shale-gas production in China, the EU and Africa are mostly for domestic uses not allowing them to expand in international trade.

Under this world context the PRIMES-TREMOVE transport model was then used to quantify a scenario with 60% emission reduction in the transport sector without electro-mobility but with GTL imports into the EU27. The quantification resulted in additional biomass, which according to the results of the biomass supply model needs mainly to be imported. In a context of global climate action, the sustainability of such a scenario is questionable because of possible adverse affects of large biomass imports by Europe. A further variant of the scenario was then quantified assuming limitation of biomass to the amounts quantified in the dominant biomass scenario which are compliant with sustainability criteria. The only way to further reduce emissions and obtain the 60% emission reduction target is to accelerate modal shift and take measures towards reduction of transportation activity. The GTL variants therefore reach the limits of the possibilities in the EU transport sector regarding the emission reduction target. The GTL scenario without biomass constraint shows a case in which sustainability limits might be breached; whereas the GTL scenario with biomass constraint reflects a scenario with limited options for emissions reduction therefore resulting in activity reduction and modal shifts.

A Strength, Weaknesses, Opportunities, and Threats (SWOT) analysis was carried out to provide a comprehensive social-economic comparison of the scenarios. Key SWOT indicators such as the technological feasibility, scalability, social and user acceptance of different vehicles were presented in detail for each scenario and taking into consideration the dominant fuel-technology combination. Among the strengths of the battery success case is the diversification of energy sources, while range limitation imposed by battery electric vehicles and higher vehicle capital costs are recognised among the weaknesses. As regards the dominant biomass case, the main strength is considered the fact that the dominant vehicle technology remains the ICE which is a mature technology undergoing significant improvements in terms of energy efficiency. Sustainable biofuel production and the limitations in land availability are among the main weaknesses considered in the dominant biomass scenario.

This study sought to verify the contributions of different fuel-technology combinations in achieving the reduction of 60% in emissions in the transport sector, while maintaining similar levels of activity in road transport (therefore excluding, by scenario definition, large scale modal shift towards non-road or non-engine transport modes). For this purpose, it is necessary to develop alternative vehicle technologies as well as the related infrastructure for alternative energy carriers. There is no solution which can be used for all transport modes, as the only available energy carrier for this purpose, biofuels, cannot be produced to the amounts necessary in a sustainable manner; biofuels should therefore be used selectively for transport modes where electric vehicles and fuel cells are not expected to be technically viable. For passenger cars and LDVs the development of battery electric and fuel cell vehicles should be pursued, keeping in mind the different upfront costs of the two technologies.

To achieve the cases as those quantified within this study, complex policy strategies need to be developed. The policy which needs to achieve high emission reductions in the transport sector goes beyond “pure” transport policy: in case of electro-mobility coordinated action is needed to ensure that the energy system is able to produce electricity or hydrogen in a carbon free manner and in all cases to a lesser or greater extent the biomass supply industry needs to develop. The current biomass supply industry is almost inexistent compared to the levels required by any of the cases considered within this study; this would need to include the development of the feedstock supply (agriculture) but also the development of the conversion industry (e.g. large scale bio-refineries) and the supply logistics both from feedstock producer to conversion industry and from the conversion industry to the end user. Further policy needs to be in place to ensure the deployment of the necessary infrastructure for refuelling or recharging. The policy instruments therefore have to be broad, flexible and have to anticipate technology development.

The interaction between technology-cost performance development, infrastructure development and the regulatory environments is a crucial element for the achievement of decarbonisation for road transport. The development of technology is essential to achieve the target of decarbonisation as well as the construction of the infrastructure and the stability of the regulatory framework to give the necessary security to investors for the future market uptake of their products. The infrastructure and the regulatory framework therefore need to be decided before technological uncertainties are fully resolved; considering the risk of focusing on only one technology at least in the short to midterm the structures should allow for the development of more technology-fuels in parallel. The development of biofuels for non-road transportation modes is projected to be necessary to substitute the remaining oil consumption in order to achieve substantial emission reductions, assuming the sustainable production of biofuels.

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List of Abbreviations

ACEA, JAMA, KAMA	Automobile Manufacturers Associations
B100	Biodiesel
BEV	Battery Electric Vehicle
BtL	Biomass to Liquid
CCGT	Combined Cycle Gas Turbine
CCS	Carbon capture and storage
CDM/JI	Clean Development Mechanism - Joint Implementation
CHP	Combined heat and power
CIS	Commonwealth of Independent States
CNG	Compressed Natural Gas
CNG	Compressed natural gas
CO	Carbon monoxide emissions
COP	Coefficient of Performance
CTS	Clean Transport System
DG	Directorate General
DG CLIMA	Directorate General for Climate Action
DG ECFIN	Directorate General for Economic and Financial Affairs
DG ENER	Directorate General for Energy
DG MOVE	Directorate General for Mobility and Transport
EMA	Engine Manufacturers Association
E85	Fuel mixture of 85% ethanol and 15% gasoline
EU	European Union
ETS	Emission Trading Scheme
EU-15	15 Member States of the European Union until 1 May 2004 (Belgium, Denmark, Germany, Greece, Spain, France, Ireland, Italy, Luxembourg, the Netherlands, Austria, Portugal, Finland, Sweden and the United Kingdom).
EU-27	27 Member States of European Union
EUROSTAT	Statistical Office of the European Communities
FAME	Fatty Acid Methyl Ester
FCEV	Fuel Cell (Electric Vehicle)
FT	Fischer-Tropsch (Synthesis)
GDP	Gross Domestic Product
GIC	Gross Inland Consumption
GtL	Gas to Liquid
HC	Hydrocarbon emissions
HDV	Heavy Duty Vehicle
ICE	Internal Combustion Engine
IEA	International Energy Agency
IPPC	Integrated Pollution Prevention Control
LDV	Light Duty Vehicle (passenger or freight)
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NM-12	12 Member States that acceded to the EU in 2004 and 2007(Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia)
NO_x	Nitrogen oxides emissions
OECD	Organization for Economic Cooperation and Development

PHEV	Plug-in Electric Vehicle
PM	Particulate matter emissions
PV	Solar photovoltaic
R&D	Research and Development
RES	Renewable Energy Sources
TTW	Tank-to-Wheel
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WTT	Well-to-Tank
WTW	Well-to-Wheel
JRC	Joint Research Centre

List of Units

bbl	Oil barrel
bcm	Billion cubic meters
boe	Barrel of oil equivalent
gCO_2/km	Gramm CO_2 per kilometre travelled
kg	Kilogramme
km	Kilometre
kW	Kilo-Watt
l/100km	Litres consumption per 100km travelled
Mb/d	Million barrels per day
Mbl	Million barrels
MEuro	Million Euro
Mt	Million metric tonnes
$MtCO_2$	Million tonnes of CO_2
Mtoe	Million toe
MW	Mega Watt, or 10^6 watt
MWh	Mega Watt Hours, or 10^6 watt hours
pa	per annum
pkm	Passenger-Kilometre (one passenger transported a distance of one km)
t (tons)	Metric tonne, or 1000 kilogrammes
tcm	Tera-cubic meters
tCO_2	Tonnes of CO_2
tkm	Tonne-Kilometer (one tonne transported a distance of one km)
toe	Tonne of oil equivalent, or 10^7 kilocalories, or 41.86 GJ (Gigajoule)
TWh	Terra Watt-hour, or 10^{12} watt hours

1 Introduction

The Clean Transport Systems Study was commissioned by DG Mobility and Transport. This represents the final report of the Clean Transport System Study.

In view of the EU's GHG emission reduction targets of 80-95% by 2050[8] compared to 1990 and the expected depletion of oil reserves, all sectors should decarbonise and reduce their dependency on oil. Currently the transport system is dominated by petroleum products which account for 97% of overall energy demand in the sector. Ultimately oil supply is limited: current known reserves of conventional oil represent just over 40 years (BP 2010) of current oil use. Undiscovered resources which are subject to considerable uncertainty could increase this figure to around 70 years (USGS 2000). On the other hand world demand for oil is steadily increasing and is driven to a large extent by world transport needs. Additionally, the extensive use of oil products also causes CO_2 emissions that have adverse impacts on the environment. In the EU the use of oil, also causes dependency on imports from a limited number of world regions, some of which are considered politically unstable.

Any ambitious GHG emissions reduction pathway involves significant cut of emissions also in the transport sector, which is among the most inflexible sectors for fuel-mix changes. Reducing emissions in transportation will imply irrespective of the manner significantly lower consumption of oil which will have beneficial effects regarding security of supply concerns. In that sense, adopting an ambitious emission cut target for the transport sector dominates over the oil independence objective.

The Impact Assessment of the "Roadmap for moving to a competitive low carbon economy in 2050" showed that transport-related emissions of GHG should be reduced by around 60% by 2050 compared to 1990 in order to achieve a reduction of GHG emissions that is consistent with the long-term requirements for limiting climate change to 2 °C. In March 2011 the European Commission adopted the White Paper - Roadmap to a Single European Transport Area [9], which proposes a series of policy measures to achieve the 60% GHG emissions reduction goal.

This study, which started in September 2010, explores possible contributions of fuel-technology combinations in order to achieve the CO2 emission reduction target set by the White Paper. Other objectives set by the White Paper (e.g. limiting the growth of congestion) were not within the scope of the current study.

The European Expert Group on Future Transport Fuels has examined different fuel-technology combinations for the transport sector and delivered a report which provides an overview of the possibilities and assesses advantages and disadvantages of deployment in the market. The report has benefitted of an extensive consultation process involving producers of fuels and technologies and other stakeholders. There are several options for the transport sector to reduce emissions and substitute oil consumption. A shift towards alternative fuels which are

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[8] http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/110889.pdf

[9] COM(2011) 144

cleaner than the ones currently in use could be made; biofuels, electricity and hydrogen could become important energy carriers in the long-term. Switching towards alternative fuels implies improvement of the existing technologies or introduction of innovative ones. Improving the efficiency of the internal combustion engines could lead to an effective use of the limited biomass resources. Introduction of new technologies such as electric powertrain systems could use energy carriers without CO_2 tailpipe emissions such as electricity or hydrogen. In fact, high technological development would be required for the market competitiveness of such fuels and technologies.

Each option has specific advantages (and disadvantages) which relate to a specific market and policy context in which they are analysed. The aim of the present study is to evaluate the possible contribution of possible fuel-technology combinations in specific policy contexts, by providing a systems analysis assessment of the options. The study includes a quantification of transport system scenarios using the PRIMES-TREMOVE transport model developed by E3Mlab of National Technical University of Athens (NTUA), an analysis of the scenarios quantified carried out by E3Mlab, a SWOT analysis conducted by Ecorys and a literature review conducted by Exergia.

The following three scenario-storylines were developed and subsequently analysed:

- **Dominant electricity** storyline; with two variants one with strong competitive advantage of vehicle technologies based on batteries and one with additionally great improvement in costs and performance of fuel cell technologies
- **Dominant biomass** storyline; success with production and market diffusion of new generation biofuels
- **“Renew”** storyline, a combination of elements of the previous two scenario-storylines, with again two variants, one with higher success in battery driven vehicles and one with higher success in fuel cells.

All the above mentioned scenario-storylines and variants were conceived in the context of the White Paper 60% CO_2 emissions cut goal. The scenarios are dynamic projections of the transport sector for each EU member state to the horizon of 2050.

The scenario-storylines involve assumptions about the drivers of dynamic changes in the transport sector. Such drivers include the technology progress, the future availability of alternative fuels and infrastructure and the White Paper instruments and targets.

Among the policy instruments future regulations on vehicles will play an important role. For analytical and explanatory purposes, the current study has evaluated two alternative vehicle regulation designs, one focusing on CO_2 emissions by vehicle and one focusing on energy efficiency.

The PRIMES-TREMOVE model was used to quantify 10 projection cases which assume different rates of technology development, different policy drivers and different assumptions regarding fuel distribution infrastructure development. Three assumption categories were assessed in detail: the efficiency progress of the vehicle technologies, the future ranges of the technologies (e.g. battery electric vehicles) and the future development of fuel distribution infrastructure. The detailed quantitative projections of the transport sector have been complemented by projections of the entire energy system and the fuel production systems for which the PRIMES and the PRIMES-Biomass models have been used. Well-to-Wheel analysis has been carried out using this model suite.

The current report is structured as follows. Firstly a description of the general methodology and the PRIMES-TREMOVE transport model, used to quantify the scenarios is presented. Section 3 presents assumptions about vehicle technologies, fuels and the infrastructure. Section 4 describes the Reference scenario considered in the modelling exercise and the assumption about the overall energy system context and the decarbonisation targets which are taken into account for the quantification of scenarios. Sections 6 through 8 analyse the results by providing tentative answers to stylised policy questions as the following:

- What is the impact of battery and fuel cell successes in the context of electromobility cases?
- What if electromobility fails to improve as expected and so new biofuels, other fuels and conventional technologies develop instead?
- At which degree development of refuelling infrastructure facilitates market diffusion of alternative fuels?
- What are the effects of CO_2 versus Energy Efficiency standards in driving deployment of alternative fuel-technology combinations?

Section 9 provides further analysis about the role of methane and LPG as transportation fuels. Section 3.7 analyses the role of blended biofuels in road transport sector in a medium term perspective. Section 10 describes the findings of projections about non-road transportation in the context of the decarbonisation cases.

Section 13 performs comparison of cases in terms of the implications on costs, final and primary energy, as well as on other criteria. Section 11.5 discusses the uncertainties underlying the different options and includes a sensitivity analysis for battery and fuel cell costs. A SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis for the cases developed for this study is presented in section 14. Section 15 provides conclusive remarks. The appendixes contain further information on the modelling tools used and a literature review providing a review of several recent studies relating to transport. Numerical results in Excel form are delivered separately.

2 Methodology and model improvements

2.1 Brief description of the model

The PRIMES-TREMOVE Transport model[10] allows studying causality effects between policy measures and other actions, and implied transformations and changes deemed appropriate within the logic of each scenario. The model project to the future the entire transport sector and produces detailed transport outlook tables for each MS and for each year (in 5-year steps) up to 2050. The model complements the overall PRIMES model by providing a more detailed and sophisticated representation of the transport sector. The PRIMES-TREMOVE transport model uses input data from the overall PRIMES model, such as fuel prices, and provides to the core model results on energy form consumption in transportation.

The PRIMES-TREMOVE Transport Model projects the evolution of demand for passenger and freight transport by transport mode and transport mean, based on a microeconomic formulation, and projects to the future fuel consumptions and emissions of GHG gases and other pollutants. The microeconomic formulation consists of two modules interacting with each other, namely, the transport demand allocation module, and the technology choice and equipment operation module.

The decision process is simulated as a utility maximisation problem with budget and other constraints in the case of the individual private passenger. The derived passenger transportation activity is allocated to transport modes such as private cars and motorcycles (both disaggregated by size), mopeds, buses for urban trips, coaches for inter-urban trips, aviation, rail, inland navigation, metro and trams where available. In the case of freight transport the decision process is simulated as a cost minimisation problem with constraints and the derived freight transportation activity is allocated to light or heavy duty trucks, rail and inland navigation.

The decision process for both the representative private agent and the firm was built largely following the TREMOVE model structure (Ceuster, Herbruggen and Logghe 2006).

The technology choice module determines the choice of vehicle technologies (generally the transportation means) that is economically optimum to be used to satisfy the various modal transport demand. The module also calculates energy consumption and emissions of pollutants per transportation mean, depending on technology, the choice of fuel and the mode of operation. Finally, a fuel choice module models the choice between different fuels, in case they are substitutable.

The choice of technology is generally the result of a discrete choice problem in which consideration of costs are taken into account. These costs depend on actual costs of transportation as well as on the cost of time (as a function of travel time and congestion).

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[10] Detailed information on PRIMES-TREMOVE transport model is included in Appendix A: PRIMES-TREMOVE Transport Model description

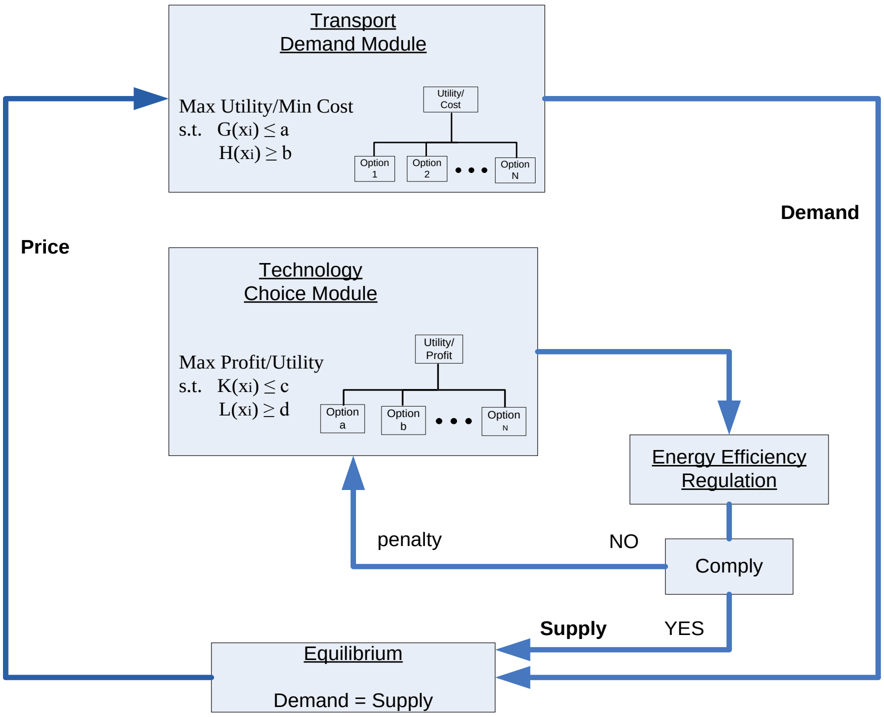
Actual costs of transportation include the capital cost of the vehicle, annual maintenance, insurance and registration costs as well as fuel expenditures. Emission costs, subsidies, taxes and other public policies also influence the choice of technology.

The technology choice module utilises the COPERT methodology (Ntziachristos and Samaras 2000) to calculate fuel consumption and pollutant emissions for each vehicle technology in the road transport sector. For non-road technology choices, other data sources have been used such as results of the SAPIENTIA project.

Both the demand allocation and the technology choice modules are dynamic over time, simulate capital turnover with the possibility of premature replacement of equipment by keeping track of equipment technology vintages.

An important new feature of the PRIMES-TREMOVE model is the implementation of CO_2 and energy efficiency standards. A schematic interaction between demand allocation module, technology choice module and the energy efficiency regulation implementation is presented in Figure 1.

Figure 1: Implementation of energy efficiency regulation into PRIMES-TREMOVE model



2.2 New model developments for the project

Several model enhancements were made compared to the standard TREMOVE model, as for example for the number of vintages (allowing representation of the choice of used cars) for the technology categories which include vehicle types using electricity from the grid and fuel cells. The model also incorporates new fuels, such as biofuels (when they differ from standard fossil fuel technologies), LPG and methane fuels. Representation of infrastructure for refuelling and recharging are among the model refinements, influencing fuel choices. A major new model enhancement concerns the inclusion of heterogeneity in the distance of stylised trips. The previous version of the model was considering a homogenous average distance trip for each category of trip. The new version considers that the trip distances follow a distribution function with different distances and frequencies. The inclusion of heterogeneity was found to be of significant influence in the choice of vehicle-fuels especially for vehicles-fuels with range limitations.

PRIMES-TREMOVE transport model is linked with the overall PRIMES model to get fuel prices, electricity and hydrogen prices, as well as specification of blended fuels, including biofuels. The transport model results are conveyed to the entire PRIMES model for further life cycle evaluations of energy supply, resources, prices, costs-investment and emissions. The possibilities and the optimal configuration of the biomass and biofuels production system are assessed using the dedicated PRIMES-Biomass Supply Model[11] which is also linked with the core PRIMES model and the transport model, taking from them demand figures and conveying to them bio-energy commodity prices. Externality costs and benefits (e.g. lifecycle emissions related to biomass and biofuels production) are evaluated through the PRIMES-Biomass Supply and the core PRIMES models.

Infrastructure development and costs are included in the model cost structure, e.g. an increase in electricity demand may induce an increase in grid investments. Refuelling and recharging infrastructure is treated specifically in the PRIMES-TREMOVE transport model. Availability of such infrastructure influences the vehicle-fuel choices.

2.3 Use of the model for policy analysis

The PRIMES-TREMOVE model, like the rest of the PRIMES model, is a system and market simulation tool which is used to quantify scenarios about future evolution of the system and the markets under assumptions about the policy and regulation, technology development, world energy market evolution and economic growth and activities. The scenario context, i.e. the scenario-related assumptions, is described through a set of exogenous technical and structural parameters and policy drivers. Among those exogenous parameters, the following technical and structural parameters play a decisive role in the transport model:

- Activities related to macro-economy
- Regulations, standards and market-oriented policy instruments
- Fuel prices (depending on the rest of the energy system)
- Technical improvements and cost changes for vehicle technologies
- Driving range for certain vehicle technologies
- Density of refuelling and recharging infrastructure

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[11] Brief description of the PRIMES-Biomass Supply model can be found in Appendix B: PRIMES and PRIMES-Biomass Models brief description

The diffusion of a technologies and the use of fuels are influenced by the policies reflected in a scenario. Policy drivers and measures can be divided into soft measures, financial and legislative measures.

Soft measures include the coordination between the public and the private sector, information campaigns, certification of services and labelling, partnerships between the public and the private sector aiming at enhancing knowledge and at using resources more efficiently at EU, national and regional level (e.g. expert groups). This kind of measure cannot be explicitly modelled with the modelling tools used in this project; indirectly nonetheless this kind of action is modelled: information campaigns and labelling as well as certification of service providers for new technologies are measures are modelled as factors improving the perception cost of technologies by the modelled decision makers, in particular regarding the adoption of new or more efficient, but also more expensive, technologies. Labelling is also modelled as enabling the consumer to become aware of the costs of operating an appliance or vehicle, thus as factor reducing perceived costs of new technologies; certification of services allowing consumers to reduce perceived technology-related risks are also modelled as factor reducing perceived costs. In the absence of such measures, the model assumes higher perceived costs for new technologies, thus discouraging their choice by private consumers. Policies that decrease the risk (technological, financing, etc.) in consumer choices can also be reflected in the model by lowering discount rates which are involved in capital budgeting decisions.

Financial or market-oriented policy instruments are explicitly modelled. Such measures include subsidies and taxes (on fuels, on cars, etc.), emission pricing, congestion pricing, externalities pricing, certificate systems (e.g. ETS), etc. Financial support to R&D is not modelled explicitly in the model; of course the possible effects of R&D on costs and performance characteristics of new technologies are reflected in the techno-economic assumptions.

Further financial instruments to be considered are ones that lead to risk reduction such as loan guarantees. These are particularly relevant for the demonstration phase of technologies, in particular for ones that require large production facilities like second generation biofuels. This can be included in the model by reducing the risk of the investment and thus reducing the discount rate in capital budgeting decisions.

Taxes or subsidies on vehicles are common drivers to incentivise technology choice and efficiency. Subsidies on new technologies, aiming at accelerating market diffusion, are modelled together with a cost recovery mechanism, for example through raising other taxes or levies. Other forms of subsidisation, like tax exemptions (e.g. registration tax) for new vehicles, are also modelled. Another way to give incentives in favour of new technology is to tax vehicles based on old technology; the model can vary tax or subsidy parameters per vehicle type, vehicle age, the energy intensity and the level of emissions.

Fuel taxation is modelled through the standard excise taxes which can be defined either in standard form, or in proportion to emissions (direct or life cycle) or energy efficiency. Taxation in the model also refers to vehicle ownership, congestion, externalities, etc. Carbon pricing through certificate systems, like the ETS, is reflected in the model as carbon taxes, when auctioning of appliances apply, or as carbon values, when allowances are distributed for free. In the latter case, carbon values influence decisions about fuels and technologies, as the carbon taxes do, but they do not entail payments by consumers and so they do not affect the budget constraint in a direct way. The level of the ETS carbon price (or the level of non ETS shadow carbon values) is determined in the core PRIMES model.

Regulation measures span a wide array of possible policies focusing on the setting of targets, standards and differentiated charges.

Targets on CO_2 intensity and the RES share in the fuel mix for the transport sector can be imposed at EU and global level. In the PRIMES-TREMOVE Transport model and the general PRIMES model it is assumed that it is applied at EU level and the level of the shadow RES values are determined in the core model. Regulations regarding the share of RES as stipulated in the EU Renewable Energy Directive are modelled in the production of liquid fuels affecting the blending of biofuels and also in the core PRIMES model regarding the RES shares in electricity, which being used in transportation also influences the transport sector RES share.

Currently tailpipe CO_2 emission standards, for example as implemented in the EU up to 2020, are regulations applying on the average fleet emissions of new vehicles; these are modelled as such and are expressed as caps on gCO_2/km. The technology and fuel choices in the model are influenced since these standards are explicitly included as constraints. Alternative forms can also be modelled, for example standards on existing fleet (included as an option in the current model). In the same way standards on energy efficiency are represented in the model, apart the EURO standards which are in place in the EU and are modelled as specifications on new car registrations. The overall energy efficiency standards are modelled as constraints applying on the average fleet of new registrations, or optionally also to old cars.

Contrasting other approaches, the PRIMES-TREMOVE model does not pre-define whether a technology is projected as “winner” or “loser”; this is a model result depending on assumptions about technologies, costs and prices and policies. Emission reduction is achieved as a result of policy drivers and constraints and projections are dynamic in a time forward manner, contrasting back-casting approaches.

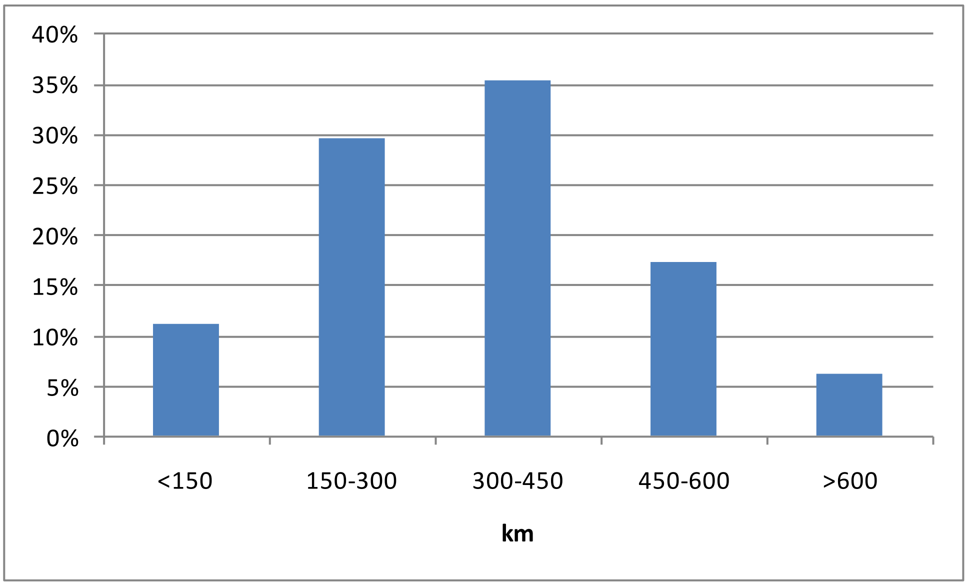
2.4 More detailed description of model enhancements for the CTS study

2.4.1 Range limitation and refuelling infrastructure density

An important new feature in the PRIMES-TREMOVE Transport model is the representation of vehicle range possibilities and the refuelling infrastructures. These are both deemed to influence the choice of vehicle technology by consumers. Conventional technologies like ICEs do not have range limitations due to the large availability of quick refuelling infrastructure whereas battery and fuel cell electric vehicles do, especially the former. The same applies to for example gas-fuelled car types because of low density refuelling infrastructure. Vehicle technologies with limited range are endogenously penalised and the corresponding perceived costs by consumer are increased.

Comparing the range possibilities of a vehicle technology against only the average trip length of a typical representative consumer is not sufficient to capture the large variety of situations that exist in reality. Approaches based on averaging fail to represent the true effects of range limitations on consumer choices. For this purpose, the model representation of trip categories was extended by introducing a distribution of trip lengths for each trip category of the model. The distributions have different shapes and standard deviations depending on the trip nature. By taking into account the distributions, the model compares the range possibilities of vehicle technology against each class of trip length within a trip category and derives cost elements from such comparison; a representative motorway trip distribution histogram can be seen in Figure 2. These cost elements are then aggregated as weighted sums for each consumer type, depending on the involvement in the various trip categories and the relative distribution shapes in each category. The numerical parameters of the model reflect strong aversion for trip cases with high discrepancy between trip lengths and range possibilities of the technologies.

Figure 2: Representative histogram for a motorway trip



Similar situations arise when refuelling or recharging infrastructure has insufficient density. The density of this infrastructure (electricity, hydrogen, gas, LPG, biogas, etc. are distinctly represented in the model) is exogenously assumed and is taken into account in cost evaluations. Infrastructure development is further disaggregated according to the types of vehicles which use the infrastructure. Different infrastructure assumptions are made for larger and heavier vehicles like HDVs and buses compared to smaller private vehicles like cars and motorcycles. The model therefore has the possibility to introduce different infrastructure assumptions depending on the vehicle type (HDVs, cars) and on the area (urban, inter-urban) under consideration; these can vary for the different cases.

2.4.2 Lower nest fuel choice module

Once the consumer has decided upon the purchase of the new vehicle, for some technologies there is the possibility to further choose between fuels. A fuel choice module has been incorporated which simulates the choice between different substitutable fuels. This module highlights consumer's behaviour upon the choice of refuelling within the context of minimizing expenses. For example a diesel vehicle technology owner, can refuel with diesel blend or pure biodiesel if the technology allows for substitution between these fuels.

2.4.3 Energy efficiency standards implementation

For the CTS study energy efficiency regulations were implemented in the model for all road transportation modes; these regulations may be activated as an alternative option to the CO_2 standards (applying on passenger cars, LDVs and powered two-wheelers) which were already incorporated in the model. Energy efficiency regulation implementation is an important new feature of the model which, as in the case of CO_2 standards, allows for assessing the impacts of such policy measures. The energy efficiency standards similarly to the CO_2 standards are applied on a TTW basis.

3 Vehicle technologies, fuels and infrastructure

This section provides essential information about vehicle technologies, fuels and the associated refuelling infrastructure, as represented in the model, focusing on the advantages and disadvantages in view of the scenario building; it is not in the scope of this report to provide detailed technological information on any of these three elements.

Currently the main fuels used in all forms of transport, road and non-road are petroleum derived liquid fuels such as gasoline and diesel. There are several alternatives, some of which are already in use in limited amounts and some of which are expected to be developed only in the future. The diffusion of energy carriers such as methane and LPG depends on refuelling infrastructure which is not widely developed at present, except in few countries. This limits their share in the energy mix of the transport sector. The cases analysed within this study assume different degrees of development in refuelling infrastructure in the future which influence market penetration of methane and LPG.

To reduce dependency on petroleum based products it is necessary to deviate from current trends and seek alternatives, but as yet no alternative fuel seems to have the potential to substitute petroleum based products by itself in the timeframe considered by the study. Scenario cases with dominance of an alternative, i.e. electricity or biofuels, and scenario cases where many alternatives compete have been examined.

Liquid fuels can either be petroleum based or biomass based; methane fuels are considered to be based on natural gas or products derived from biogas and LPG; electricity and hydrogen are considered in conjunction with the corresponding vehicle-types. Liquid and gaseous fuels use different versions of internal combustion engines (ICE), with the exception of aviation which uses turbines, while fuel-cells fed by hydrogen and battery-based vehicles involve two different storage methods of electricity which feeds an electric motor.

3.1 *Petroleum based liquid fuels*

Selected bibliographic sources: (IEA 2009),(Future Transport Fuels 2010),(Hill, et al. 2009), (JRC 2007)

Petroleum based liquid fuels are the main fuels currently used both in road and non-road transport, with the exception of rail. Crude oil is mainly imported into the EU; imports and exports of refined products complement a large refining capacity established in the EU.

There are several concerns regarding the extensive use of petroleum based products: ultimately petroleum is a finite resource; crude oil is extracted in a limited number of countries world-wide creating a high dependency from these areas, some of which are known for being politically unstable; petroleum derived products emit large amounts of GHG emissions (mainly CO_2), contributing to climate change, and other pollutants (among others PM, SO2, NOx) that generate both health and environmental concerns. Nonetheless petroleum based liquids have several advantages which render it difficult to find adequate substitutes: they have high energy density, which allows long-driving ranges and relatively low volume and weight of the fuel and are characterized by a highly flexible distribution chain.

In this model the following liquid oil based fuels are considered: gasoline, diesel, kerosene and fuel oil. With the exception of kerosene, which is used in turbines for aviation, they are used in different types of ICEs (see below).

Main vehicle technology: ICE

The main petroleum liquids used in road transport are gasoline and diesel through internal combustion engines; gasoline is mainly used in passenger cars, light duty vehicles and passenger two wheelers whereas diesel is used in all forms of road transport, except passenger two wheelers. Diesel is further used in rail and navigation. Ship engines mostly use fuel oil, with some engines being able to switch between fuel oil and diesel. For aviation kerosene is utilised mainly in gas turbines.

Infrastructure

Petroleum based liquid fuels: gasoline, diesel, kerosene, fuel oil		
Infrastructure	Existing	
Vehicle Technologies	Technology	Stage of development
	ICE (gasoline, diesel, fuel oil) Gas turbines (kerosene)	Mature technology Mature technology
Transport modes	Road transport (gasoline, diesel): passenger cars, passenger two wheelers, light duty vehicles, buses, heavy duty vehicles Non-road transport: rail (diesel) shipping (diesel, fuel oil) aviation (kerosene)	
Advantages	High energy density of fuel Vehicle technology is readily available and mature Availability of infrastructure Allows long ranges	
Limitations	Continues dependency on oil No decarbonisation	
Potential	Through advanced technologies the fuel consumption can be reduced, therefore reducing oil dependence and emissions and may pave the way for biofuels to enter the market.	

Internal combustion engines using diesel or gasoline are considered fully mature technologies. The typical range of an ICE powered passenger car is between 600 and 1000km and similar ranges can be reached by most vehicle types. The most important future development of an ICE is increased efficiency; this will allow for the reduction of fuel consumption, reduction in both GHG and pollutant emissions. One of the ways to increase efficiency is the introduction of a hybrid technology which includes a small electric motor which works together with the ICE for peak power needs. The onboard battery stores e.g. the recaptured energy mainly from braking (regenerative braking) and uses it to power the electric motor. More efficient diesel or gasoline ICEs coupled or not with an electric motor in hybrid configuration allow the reduction of fuel consumption. Market diffusion of (non rechargeable) hybrid vehicles can pave the way for the substitution of oil with other fungible liquids.

The infrastructure for the transport and distribution of the fuels is fully established with over 130000 petrol stations in the EU (Europia 2009); it is assumed that the basic infrastructure for petroleum based liquids will continue existing in the future. Both gasoline and diesel, often in several qualities, are available at petrol stations.

3.2 Liquid biofuels

Selected bibliographic sources: (Wyman 1996), (EDWARDS, et al. 2008),(Kampman, Rooijers and Faber 2006),(Howarth and Bringezu 2009),(Eisentraut 2010),(IEA 2007),(Hansen, Mikkelsen and Topsoe 2001), (Kampman, et al. 2010),(Croezen, et al. 2010), (Zanchi, Pena and Bird 2010), (Blakey and Novelli 2010),(Higgins 2007),(Rettenmaier, et al. 2008),(Croezen and Kampman 2009)

There are several kinds of liquid biofuels including ethanol and biodiesel. Currently so-called first generation technologies are used to produce ethanol and biodiesel; first generation biofuels use food crops as feedstock therefore generating competition with food resources. In future to reduce competition with food for nutritional purposes other crops are expected to be used, in particular ones that will also reduce competition in land use; technologies using non-food crops are called second, when using ligno-cellulosic materials and third generation when using other feedstock such as algae.

Ethanol is currently produced from sugar or starch rich corps such as sugar cane or beet and corn or wheat and is transformed into ethanol via a fermentation process. It is used in non-modified gasoline engines in low percentage blends or in modified engines that allow blends up to 85% (E85). In future it is expected that ethanol will be produced through gasification of ligno-cellulosic biomass thus allowing a higher variety of feed stocks to be used, thus contributing to the reduction of competition with food crops and possibly also of land-use.

The currently used biodiesel (esters and FAME) are produced from oil rich crops, through esterification of vegetable or animal fats; this kind of biofuel, as it is currently produced, also has problems of competition with food crops as vegetable oils are mainly used for nutritional purposes. Biodiesel is currently used in blended form with petroleum based diesel; but it is possible to use pure biodiesel (B100), with limited modifications to the diesel engine. Pure vegetable oil (non-esterified) can also be used in modified diesel engines.

In future it is expected that next generation biodiesel will be available; this implies the production of biodiesel from non-food crops, such as ligno-cellulosic materials, via gasification. These processes are generally called BTL (biomass to liquid) processes and mainly use Fischer-Tropsch (FT) synthesis. The use of new feedstock and new technology would allow the reduction of competition on food crops and possibly a reduction of competition of land-use. Further in BTL processes it is possible to control the output product therefore creating fuels that can entirely substitute diesel and gasoline without the necessity of engine modification.

With BTL processes it is also possible to produce fuels that can be used in aviation, as substitutes for kerosene; heavy fuel oils can also be produced.

Third generation fuels rely on the use of algae as feedstock and are also expected to produce mainly kerosene and diesel like fuels for transport activity; these technologies are still at R&D phase.

Further in the model DME is considered a biofuel option; this fuel is a simple ether and needs to be burnt in engines optimized for DME which are modified diesel engines. Currently the main production of DME is through syngas from natural gas or coal, but the same process can be used for DME produced from biomass.

The main advantages of biomass based liquid fuels are the full or partial compatibility with the currently available vehicle technologies; the use of the same infrastructure for transport and distribution; reduction of oil dependency; reduction of pollutant emissions; and an energy density comparable to the one of petroleum based liquids. Consumer acceptance however shall determine whether and to what extent the introduction of higher blends will take place. Uncertainties on compatibility issues with existing vehicles could hinder wider expansion of fuel mixtures such as E10; such was the case in Germany where consumers refused to fuel their vehicles with E10 fearing that such fuel could damage their vehicles' engine. Limitations and disadvantages include: limited availability due to land constraints and competition with food crops; uncertainty about the consequences of land-use change, mainly uncertainty about the resulting GHG emissions.

In the model biodiesel both in blended and in pure form, ethanol in blended and pure form and DME, as well as biokerosene for aviation and bioheavy for navigation are the liquid fuels considered from biomass. Other forms of synthetic fuels from coal or natural gas (CTL and GTL paths respectively) are not considered. While these fuels are being developed and used in China and the USA due the domestic availability of coal and gas in these countries, in the EU this would have no major benefits (GTL can, and should be included).

The EU imports both coal and natural gas, so the advantages experienced by other countries are not valid in the EU context. Further these technologies, although reducing oil dependency will not allow for decarbonisation, reduced emissions may occur when coupling these technologies with CCS. In the context of the EU these fuels do not provide any significant advantages and are therefore excluded for modelling purposes.

Main vehicle technology: ICE

The main vehicle technology using liquid biofuels is the ICE. When using low (less than 10%) percentage blends of biofuels in oil based fuels, no modifications need to be made to the engine; when high percentage blends or pure biofuels are used modifications need to be made. Flex-fuel vehicles are vehicles which can drive on a variety of different blends ranging up to 85%.

Through the development of synthetic biofuels it may be possible to avoid any modifications and produce fuels that run directly in conventional ICE vehicles used for conventional diesel and gasoline. Even though the biofuels have the theoretical potential to displace petroleum based liquids, the limited availability of biofuels leads to the necessity to increase efficiency (even through hybridisation). The range of the ICE does not change through the switch to biofuels; the amount of pollutants is reduced.

Infrastructure

The blended biofuels use the same distribution infrastructure as the petroleum based fuels, as is currently the case in the EU. The distribution concept for the other types of liquid biofuels would also remain the same and would not require large infrastructure investments; however blends such as E10 require new outlets and parallel infrastructure to be developed.

Liquid biofuels		
Infrastructure	Existing, as liquid petroleum based fuel infrastructure can be used	
Vehicle Technologies	Technology	Stage of development
	ICE	Mature technology, small modifications compared to petroleum based liquid may be necessary when using high blends
	Gas turbines (biokerosene)	Mature technology, as the quality of the biofuel will have to comply with fossil kerosene standards
Transport modes	Road transport (biogasoline, biodiesel): passenger cars, passenger two wheelers, light duty vehicles, buses, heavy duty vehicles Non-road transport: rail (biodiesel) shipping (biodiesel, bioheavy oil) aviation (biokerosene)	
Advantages	High energy density of fuel Vehicle technology is readily available and mature Availability of infrastructure Allows long ranges Can substitute existing fuels almost entirely Reduces pollutant emissions Reduces GHG emissions (WTW emission reduction is dependent on the crop production and emissions related to indirect land use change[(Croezen, et al. 2010),(European Environmental Bureau 2010),(Zanchi, Pena and Bird 2010)	
Limitations	Land availability Competition with food crops (in particular for 1st generation fuels) Sustainability User acceptance	
Potential	Biofuels, if sustainability criteria are met in the overall production chain including indirect land use change effects, have the potential of substituting petroleum liquid fuels without the necessity of major changes in infrastructure or in the vehicle technologies. The limited availability implies the necessity of vehicle technologies to increase their efficiency Improved technology could lead also to significant reduction in pollutant emissions compared to gasoline/diesel.	

3.3 Methane

Selected bibliographic sources: (Ahman 2010), (Brachetti 2010),(Lage 2010),(Svensson 2010),(Dudenhoeffer and Pietron 2010),(Miletto, et al. 2010)

Methane can be derived from natural gas or from biomass (or from coal but this is not interesting in view of carbon constraints); currently the main source is natural gas. The reserves of natural gas are expected to last for 30 to 40 years longer than the oil reserves; a combination of new exploration and new drilling technologies has increased the amount of available reserves over the past years and it is expected that this may continue in future. Large unconventional gas resources seem to emerge, provided that environmental issues are resolved.

Production of biogas has also increased over the past years and is expected to rise in future. Biogas can be produced by a variety of feedstock, mostly residues and waste.

Methane can be used in internal combustion engines (ICE) especially adapted to gas use; these have been in use for several years and are therefore a mature technology, although the use of gas for transport is still limited, with some regional markets, such as Italy featuring prominently. Methane is used in passenger cars, light duty vehicles, buses and a very limited extent for heavy duty trucks. It is currently not used for non –road transport, although there is growing interest in LNG for shipping (DNV 2009), in view of stricter emission regulations for shipping by the IMO (currently LNG as fuel is only used in LNG container ships).

Currently methane is mainly used as compressed natural gas (CNG) in transportation, but LNG could become more available as LNG imports in the EU are increasing and tanks are being built on the coasts. It could be used mainly in long-distance heavy transport (e.g. Blue corridor project), (UNECE 2003).

The main advantages of methane include: lower CO_2 and to some extent also lower pollutant (especially particulate matter) emissions compared to diesel or gasoline; the possibility to import from a larger group of countries, as well as (decreasing) production inside the EU; the existence of an existing distribution and transport network; and the existence of a mature and energy efficient vehicle technology. The disadvantages include: CO_2 emissions still remain, the fuel therefore cannot lead to ambitious decarbonisation of the sector unless the switch from natural gas to biogas is made; remaining import dependency.

The methane fuelling options considered in the model are the typical ones found in the EU: natural gas; natural gas blended with hydrogen; natural gas blended with biogas; and pure biogas.

Main vehicle technology: ICE

The main technology to use methane is via an internal combustion engine, just as for gasoline and for diesel. Methane is generally stored as compressed natural gas (CNG) on a passenger vehicle; therefore the vehicle has a pressurized gas tank instead of the tank for liquid fuels, although some vehicles are configured as bi-fuels and therefore have a gas tank and a tank for liquid fuels (normally gasoline). The lower energy density of the methane implies that on average the driving range is slightly lower than an equivalent ICE gasoline or diesel car; also the onboard storage space is reduced due to the tank.

Infrastructure

In Europe there is a large natural gas network which comprises large areas as natural gas is used for domestic and industrial applications; currently only a limited number of countries (among which Germany, Switzerland, Austria, Netherlands and Italy) have an existing network of gas refuelling stations. For wider use of gas powered cars a much larger refuelling network will be necessary; in some countries only fleet vehicles are running on natural gas, so that the distribution infrastructure is only available to a specific group of users/vehicles. The use of bi-fuel cars, e.g. CNG-gasoline combination, can reduce problems related to the lack of infrastructure.

If the adequate standards are applied for the production of biogas, it will be possible for the biogas to be injected into the existing natural gas grid, thus allowing a seamless shift from natural gas to biogas. Although biogas can be made from a wide variety of biomass feedstock including waste and manure which do not need specialised crops, there are limitations in the amount of biogas to produce and the use of biogas in transportation, as other sectors will also require the use of biogas to decarbonise and reduce energy dependency.

Methane from natural gas and biogas		
Infrastructure	the natural gas grid exists the refuelling infrastructure has to be expanded	
Vehicle Technologies	Technology	Stage of development
	ICE	Mature technology
Transport modes	<u>Road transport</u>: passenger cars, light duty vehicles, buses, heavy duty vehicles <u>Non-road transport</u>: shipping (demonstration phase)	
Advantages	Reduction of CO_2 and to some extent pollutant emissions Reduction of petroleum dependence Vehicle technology is readily available and mature Possibility to substitute fossil based gas with biogas without other changes	
Limitations	Does not allow ambitious decarbonisation, unless biogas is used Tanks in particular for bi-fuel vehicles may reduce payload Lower energy density of fuel implies lower ranges compared to liquid fossil fuels Biogas has until now limited availability; it is mainly produced from waste products does therefore not have the limits of liquid biofuels regarding land use, but is limited by the waste supply	
Potential	Readily available technology implies availability in the short-term and availability as a backstop technology should breakthroughs not occur in more advanced technologies Possibility of substitution with biogas allows a shift towards renewable energy without further changes being necessary	

3.4 LPG

<u>Selected bibliographic sources:</u>(AEGPL 2009)

LPG refers to a gaseous fluid containing mainly propane and butane; it is mainly a product of oil refining and natural gas processing. LPG is used mainly for passenger cars and light duty vehicles, but also for buses and to a very limited extent for heavy duty vehicles. It is currently not used for non-road transport. LPG is used via internal combustion engines; previously cars using LPG were mainly retrofitted cars, but now LPG cars are available from the manufacturers. They often operate bi-fuel with gasoline, to avoid the problem of the lack of infrastructure in some areas.

In future it may be possible to produce also biomass based LPG, although this technology is still at an R&D phase.

The advantages of LPG are the reduced CO_2 emissions, and that it allows a better use of fossil fuels. Due to the fact that LPG is mainly a by-product of refineries there is only limited availability of LPG, which needs to be shared between different sectors. Only the introduction of bio-LPG could allow for independence from petroleum[12]. It is nonetheless a good short time solution to improve air quality by reducing pollutant emissions, in particular considering the fact that an oversupply of LPG is expected in the coming years which should improve the economics and reduce the need for support through low excise duties.

LPG		
Infrastructure	LPG distribution infrastructure is available Refuelling infrastructure has to be expanded	
Vehicle Technologies	Technology	Stage of development
	ICE	Mature technology
Transport modes	<u>Road transport</u>: passenger cars, light duty vehicles, buses, heavy duty vehicles Non-road transport: n/a	
Advantages	Reduction of CO_2 emissions Vehicle technology is readily available and mature Expected surplus of LPG should improve economics and reduce need for economic incentives	
Limitations	Does not allow full decarbonisation, unless bioLPG is developed Tanks in particular for bi-fuel vehicles may reduce payload Lower energy density of fuel implies lower ranges BioLPG is still at R&D phase	
Potential	Readily available technology implies availability in the short-term and availability as a backstop technology should breakthroughs not occur in more advanced technologies Possibility of shift towards bioLPG should this become available	

Main vehicle technology: ICE

Also LPG vehicles rely on the ICE technology, but the engines, as methane vehicles, cannot work with other fuels, unless the cars are developed as bi-fuel cars. Compared to gasoline and diesel cars the use of LPG allows a reduction of air pollutants and a reduction of CO_2 emissions; thus increasing air quality. Similarly to CNG cars, LPG cars also require a pressurized tank to contain the fuel and in particular if the vehicle contains also a tank for liquid fuel, the payload

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[12] Bio-LPG is not yet included in the model due to the lack of data and to the fact that the quantities found in the literature did not justify its introduction in the cases quantified in this study.

of the vehicle may be reduced due to the greater volume necessary for the onboard storage of the fuel.

Infrastructure

There is an existing distribution infrastructure for LPG; similarly to natural gas also LPG serves for residential and industrial purposes as well as transport. There are about 25000 LPG refuelling stations in the EU the majority of which can be found in Poland, Germany, Italy and Bulgaria. As is the case for natural gas further development of the refuelling infrastructure will be necessary for an increase in LPG share in transportation. Due to the supply limitations, LPG will remain a supporting fuel.

3.5 Hydrogen fuel cells

Selected bibliographic sources: (Thomas 2009),(Wuster, et al. 2010), (Michael and Bunger 2009), (Offer, et al. 2011), (Gielen and Simbolotti 2005), (McKinsey 2010), (Kouvaritakis 2007), (ArgonneNationalLaboratory 2004)

Hydrogen is an energy vector; it can be produced through a multitude of primary energy the most common of which are currently methane reformation and electrolysis. Because of its high maturity and in the context of decarbonised power generation system electrolysis is the main pathway considered for hydrogen production. Hydrogen can be used both in ICEs and can be converted via a fuel cell into electricity to power an electric motor. Currently it is used mainly at a pre-market stage in passenger cars, light duty vehicles and buses.

The main advantages of hydrogen are that it has no tailpipe emissions aside from water vapour, and as it can be produced from electricity has a potential of being decarbonised when the power generation system is decarbonised. The overwhelming obstacle for the hydrogen is the cost of the fuel cell vehicles (stack and system). Although currently there is no infrastructure for hydrogen, it is expected that if fuel cells were to become competitive, the infrastructure would no longer be a barrier.

Hydrogen is not considered as a fuel for ICEs because the efficiency of a hydrogen ICE is much lower than a fuel cell ICE. The building of a hydrogen infrastructure would not be justified when using the hydrogen in an ICE. Natural gas and LPG are excluded as fuel for fuel cells in this model on the grounds that the use of natural gas and LPG is more cost-effective in an ICE motor in the context of scenarios aiming at reducing emissions. The use of natural gas and LPG in fuel cells would require on-board reformers requiring high temperatures (approx. 600-900°C (Nichols 2003), which represent a considerable additional cost and represent high energy loses thus not justifying the expense of the fuel cell. Additionally tailpipe emissions would occur thus there would be no further environmental justification for the use of this more expensive option.

There is only one other fuel that could be justified in the context of fuel cells: methanol. Methanol would not require the expensive infrastructure necessary for hydrogen, as methanol is in liquid state at ambient temperature. The infrastructure for methanol would be similar to that of liquid oil fuels with the difference that methanol is more corrosive and toxic. Methanol which is similar to ethanol in many aspects has not been widely considered in recent years because of its higher toxicity and lower energy density; in combination with fuel cells it would nonetheless have advantages because of the higher proportions of hydrogen to carbon atoms and contrary to the temperatures necessary for natural gas reformers a methanol reformer only needs temperatures around 260°C (Nichols 2003). There are nonetheless two main problems that lead to the exclusion of methanol in this study: firstly the production of methanol in a sustainable way is problematic[13] whereas the production of hydrogen having numerous production paths allows more opportunities for oil independence and decarbonisation, secondly the decisive element for the development of fuel cells is not the infrastructure but the decrease in the costs of the fuel cell itself; if this hurdle is overcome the development of a hydrogen infrastructure will probably not be problematic.

Hydrogen (fuel cell electric vehicles)		
Infrastructure	Transport and distribution network is not available Refuelling infrastructure needs to be developed	
Vehicle Technologies	Technology	Stage of development
	Fuel cell electric vehicle	Electric motor mature; fuel cell in R&D stage
Transport modes	Road transport: passenger cars, light duty vehicles, buses, heavy duty vehicles Non-road transport: shipping (R&D stage)	
Advantages	Elimination of tailpipe CO_2 and pollutant emissions Elimination of oil dependence	
Limitations	FCEV still have very high costs and deployment until now has been limited Both large scale hydrogen production facilities and the infrastructure needs to be developed	
Potential	Hydrogen power FCEV have the potential of eliminating petroleum dependence and emissions[14], subject to large infrastructure investments	

Main technology: fuel cell electric vehicle (FCEV)

Hydrogen is a way to store the electricity on board needed for an electric engine; the transformation technology used to generate electricity from hydrogen is the fuel cell. A fuel cell converts hydrogen into electricity with the help of an oxidant (oxygen or air is normally

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[13] The main production routes for methanol are from natural gas conventional or unconventional resources, coal and petroleum, which only combined with CCS could provide emission reductions; the biomass path would possibly limit the amount of methanol available due to land use limitations. The future production route of methanol from hydrogen and CO2 is not yet a proven technology at large scale and the provision of the process with hydrogen and CO2 may be problematic (George, Goeppert and G. 2006).

[14] The overall WTW emission reduction depends on the ways of production of hydrogen; in this project electrolysis will be the production method. It is assumed that the entire energy systems aims at decarbonisation and that therefore the electricity used for electrolysis will be decarbonised to a high extent by 2050.

used) and an electrolyte, which generally specifies the characteristics of a fuel cell, defining its type and name. Hydrogen needs to be stored on board in a pressurized tank at 350 or 700 bar; this allows the range of the FCEV to be closer to the ranges of ICE vehicles. The main disadvantage of fuel cells is their high cost which is due to the catalyst used which is often platinum or other expensive metals. Research is being carried out to reduce, eliminate and/or recycle the catalysts to reduce the costs of fuel cells.

Fuel cell vehicles are applicable to all road transport; concepts are being developed to apply fuel cells also in shipping,[15] whereas no evidence has been found to applications in rail or aviation. For the purpose of this project fuel cell electric vehicles will be used only for road transportation.

Infrastructure

Another main issue with the use of FCEV is the necessity to develop a hydrogen infrastructure which is currently not available. The entire transport, distributional and refuelling infrastructure needs to be built. Whereas for electricity a modular construction of the infrastructure is possible, for hydrogen a coordinated build up is necessary.

The possibility to use hydrogen has the advantage compared to electricity of having no range limitations similar to the conventional ICE vehicles used today; on the other hand this would imply that a large distribution network needs to be put in place.

3.6 Electricity

Selected bibliographic sources: (McKinsey 2009), (Offer, et al. 2011),(Nemry, Leduc and Munoz 2009),(Rode and Andersson 2001), (Thomas 2009), (Dasgupta 2008), (Hybridev.com 2010), (Blueprint for a secure energy future 2011)

Electricity is an energy vector which can be produced by a large variety of primary energy sources, both fossil fuels, renewables and nuclear. To use electricity in a vehicle, electric motors are used, which are highly efficient. The electricity can be supplied to the motor either by direct link to the electricity grid (e.g. trolley buses or rail) or it can be stored on board through batteries. For road transport the most common system is through on board batteries; the system can work either as a pure battery electric vehicle or as a plug-in electric hybrid vehicle in combination with an internal combustion engine.

The advantages of electricity are that there are no tailpipe emissions and that the power generation sector has the potential to become entirely decarbonised, thus leading to a decarbonised transport sector. The disadvantages of electricity are currently related to the on-board storage possibilities (batteries) that until now do not allow ranges that are common in ICE vehicles and the costs that are extremely high.

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[15] http://www.lowcarbonshipping.co.uk/ (last visited January 2011).

Main technology: off-grid battery vehicles and on-grid vehicles

The use of electricity as an energy vector for the transport sector will create a paradigm shift. The electric engine is a mature technology, which is used in many industrial applications and has a much higher efficiency compared to an ICE engine. Benefits of an electric motor are the elimination of all tailpipe emissions, and of noise. In battery electric vehicles, a battery or battery stack is used to supply the electricity to the electric motor. The main difficulty about this system is the high cost of the batteries and the range limitations due to the battery weight and cost. Battery charging is assumed to occur from the power grid through an appropriate charging infrastructure. Current battery electric vehicles have ranges up to approx. 150km and have an additional cost of about 10000€ to 15000€. The uncertainty in the future development of battery costs is the main impediment to a large scale development of electric vehicles together with the range limitations. In this study we assume different developments (and speed of development) for batteries in the different cases that imply both an improvement in the battery/engine technology (allowing for higher ranges without a significant increase in mass or volume) and a development in the costs of batteries. The assumptions for the different cases are explained in the scenario case sections.

Two further technologies, mainly for road transport, use electric motors in combination with other technologies: plug-in electric vehicles and range extender vehicles.

The plug in-hybrid is a vehicle which has both an electric motor and an ICE, but unlike the conventional hybrid it also has a larger battery which can be charged from the grid. This generally allows the vehicle to have an all electric range of 40 to 80km, which are normally sufficient to cover the daily requirements of an average driver. The existence of an ICE powered with diesel or gasoline allows for the so-called range anxiety to be eliminated as after the all-electric range has been exploited the car automatically switches to its ICE.

Another technology also eliminates range anxiety: the range extender vehicles. These vehicles are being conceived with the following configuration: an electric motor is power by small batteries that are charged by an onboard electricity generator powered by gasoline or diesel. This configuration allows reduced fuel consumption while maintaining the same ranges as conventional ICE vehicles. Nonetheless although these vehicles have the potential to enormously reduce the amount of liquid fuel consumption, they are not able to entirely decarbonise the transport sector, unless biofuels are used.

Battery electric vehicles are available for all different road transport modes, but they are at different stages of development and most still require a major improvement in battery technologies for widespread deployment of the technology. There is no evidence of battery electric technology being used in shipping (except for very small recreational vessels), aviation or rail.

For rail and road transportation the use of power directly from the grid, such as in trolley buses or in trains with overhead lines, is a mature technology. The major impediment to the widespread deployment of the technology is related to the infrastructure development which is expensive and has problems of public perception as overhead lines can be considered a visual disturbance in particular in historical city centres.

Electricity (electric vehicles)		
Infrastructure	Power grid is available Recharging infrastructure needs to be built Grid needs to be strengthened	
Vehicle Technologies	Technology	Stage of development
	Battery storage with electric motor (BEV)	Electric motor is mature technology; battery storage in R&D stage
	Plug-in hybrid EV (PHEV)	Motor technology mature; battery storage in R&D stage
	Range extender vehicle	Motor technology mature; system in R&D stage
	Grid connected vehicles	Mature
Transport modes	<u>Road transport (off-grid)</u>: passenger cars, light duty vehicles, buses (also on-grid), heavy duty vehicles Non-road transport (on-grid): rail	
Advantages	Potential elimination of oil dependence (BEVs and on-grid vehicles) Elimination of tailpipe CO_2 and pollutant emissions (BEVs and on-grid vehicles)[16]	
Limitations	PHEV and range extender vehicles allow for maintenance of current conventional vehicle ranges, but do not allow elimination of emissions or full oil independence BEVs currently have low ranges due to limitations of the battery storage capacity Grid connected vehicles can only operate where overhead lines are available	
Potential	In urban areas where short ranges are required and co-benefits such as air pollution reduction and noise reduction are important, BEV and grid connected vehicles have a high potential The current limitations of range may limit the development to urban areas	

Infrastructure

Extensive grid infrastructure is already in existence in the EU therefore “only” the recharging infrastructure needs to be developed. The charging infrastructure should allow for a large number of slow charging points and a limited number of fast charging points. The amount of slow charging points should allow the users to have the security of finding a charging point in places where their vehicle is parked for larger amounts of time; fast charging points are to be installed in points with large traffic flows or on motorways, providing for the extension of the range of the vehicle.

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[16] The emissions of the electricity production are dependent on the power generation; in this project it is assumed that in the scenarios the entire energy system will aim at decarbonisation, therefore in the long-term power generation will be almost fully decarbonised.

3.7 Biodiesel and ethanol blends in road private transport sector

The use of biofuels in road transport sector lies among the important factors for reducing CO_2 emissions and decreasing the use of fossil based fuels such as diesel and gasoline lessening in such a way the dependence on them. Their contribution is particularly important also in the long term for the transport market segments in which new carbon-free carriers can not contribute because of technical limitations.

Biodiesel and ethanol are currently being used in small blended ratios with diesel and gasoline respectively ensuring proper engine and vehicle operation without need for engine modifications.

3.7.1 Ethanol

Recommended limits for ethanol use in spark ignition engines are currently set up to a maximum share of ethanol of 10% in gasoline[17]; E10 mixture can be used by all spark ignition vehicles without voiding the vehicle's warranty according to automobile and engine manufacturers. ACEA, EMA, JAMA and ALLIANCE of Automobile Manufacturers recommend using E10 in spark ignitions engines; higher ethanol mixtures though are currently not recommended for use on non modified spark ignition engines (ACEA, JAMA and EMA 2008).

Higher blends are suitable for vehicles designed for such fuel, as the flexible-fuel (dual fuel) vehicles which are able to use all possible ethanol mixtures like E85. In flexible fuel vehicles (FFVs) ethanol blend is stored in one fuel tank[18] and the mixture is injected into the combustion chamber; microprocessors detect the ethanol blend on a pre-combustion phase and adjust accordingly the timing and the fuel injection in the combustion chamber. In such a way, combustion takes place as close as to stoichiometric conditions and does not cause damage to the engine. Additionally, the FFVs bear specific differences compared to normal spark ignition engine vehicles; several fuel system parts are different including the rubber parts and modifications in the operation of the fuel pump.

3.7.2 Biodiesel (FAME19)

Currently JAMA recommends blended biodiesel ratios up to 5%[20]; higher blended biodiesel ratios are not recommended for the existing compression ignition engines unless the vehicles are specially designed. For higher ratios of biodiesel JAMA strongly recommends the use of HVO (hydro-treated vegetable oil) or BTL for production of FAME biodiesel (JAMA 2009).

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[17] Ethanol fuel mixtures are denoted with the "E" followed by the percentage of ethanol in the mixture by volume. For example E10 stands for 10% ethanol by volume and 90% gasoline.

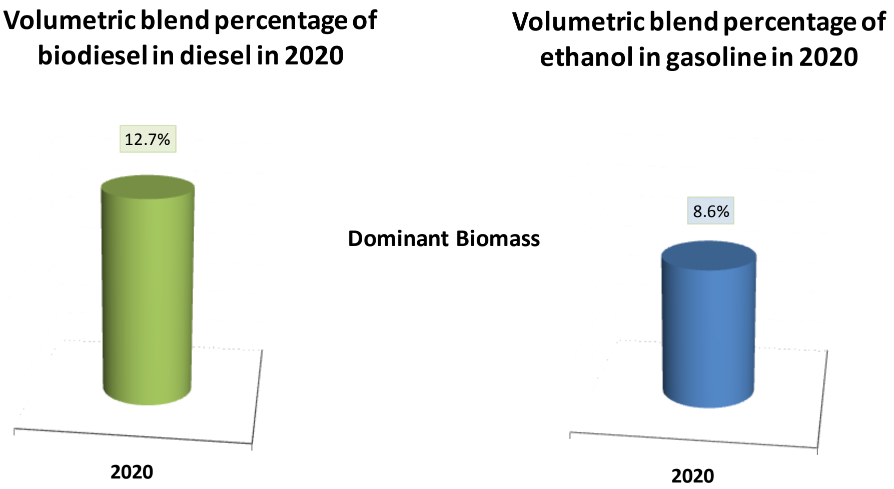
[18] Flexible fuel vehicles (dual fuel) differentiate from the bi-fuel vehicles which are equipped with two separate fuel tanks allowing for switching from one fuel to the other.

[19] FAME (Fatty Acid Methyl Ester)

[20] Biodiesel mixtures are denoted with the "B" followed by the percentage of biodiesel in the mixture; B20 stands for 20% biodiesel and 80% diesel

The European diesel fuel standards EN 590:2009 recommend diesel blends with up to 7% biodiesel (B7) provided that FAME biodiesel meets the European FAME standard EN 14214:2009. In other words, according to the Diesel Fuel Injection Equipment Manufacturers Common Position Statement (2009) once FAME biodiesel complies with the EN 14214:2009 then the resulting blend with diesel shall meet the EN 590:2009 standard. Extensive revision of the aforementioned diesel and FAME standards in the near future will be required to officially approve mixtures up to 10% (FIE 2009). According to AGQM (Association for Quality Management of biodiesel) the aim is to increase the blended biodiesel ratios even beyond 10%.[21].

Figure 3: Volumetric blend percentages of biodiesel in diesel and ethanol in gasoline in 2020 for passenger cars.



In the US, the quality of FAAE (Fatty Acid Alkyl Esters) biodiesel blends ranging from 6% to 20% should comply with the ASTM D7467 specification in order to be used in compression ignition engines. Companies like Chrysler already support B20 blend as a fuel and certified that the new diesel engines of Grand Cherokee would be designed to run on B20.

3.7.3 Modelling assumptions

In the PRIMES-TREMOVE transport model the volumetric blend percentages of biodiesel and ethanol in gasoline and diesel respectively in 2020 are approximately the same in all cases considered and represented in the model. Major differences across the cases are observed mainly beyond 2020.

The volumetric blend percentage of ethanol in gasoline for cars in 2020 does not exceed 8.5% as shown in Figure 3; this indicates that the car fleet running on gasoline is able to refuel with E10 mixture without modifying the engine or other parts of the car. According to automobile

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[21] A currently running project of the RICARDO Biofuel Consortium aims at measuring the impact of use of different biodiesel blends in a compression ignition engine and the effects on the cylinder pressure http://www.agqm-biodiesel.de/index.php?menu_sel=37&menu_sel2=45&menu_sel3=&menu_sel4=&msg=243, http://www.agqm-biodiesel.de/index.php?menu_sel=37&menu_sel2=44&menu_sel3=&menu_sel4=&msg=245

and engine manufacturers E10 mixture is suitable for cars equipped with spark ignition engine and its use does not void the warranty.

As far as biodiesel is concerned, the blend ratio used in the PRIMES-TREMOVE model reaches 12.7% by volume in 2020. This ratio is higher than current technical engines specifications (7%); however technical progress towards blends with higher biodiesel percentages shall probably justify the volumetric blend percentage of 12.7% assumed in 2020 for this study. In such case diesel powered cars shall be equipped with engines being able to run on B10 or even B20 by 2020.

3.7.4 Biofuels and CO_2 emissions

Energy consumption in non road transport modes in all cases considered in the CTS study is assumed to follow a similar projection trend till 2050 with only slight deviations. Changes in assumptions considered between the cases mainly concern road transportation. Efficiency learning curves for non road transport modes are assumed identical for all scenarios. Biomass supply to meet demand for biofuels is projected to the future using the PRIMES-Biomass model, which also evaluates CO_2 emissions for biomass supply.

3.8 Summary of technologies and fuels considered

In this study we consider the technology and fuel combinations that are available today and are being tested at a large scale. Conventional technologies, e.g. ICEs with diesel or gasoline, are considered alongside niche market technologies, e.g. LGP ICEs, and technologies requiring a technological breakthrough to obtain large scale deployment, e.g. battery and fuel cell electric vehicles. Currently it cannot be foreseen that one technology will take the lead in achieving a decarbonised transport sector.

In Table 1 the potentials of the different fuels in achieving petroleum independence, import independence and reduction of emissions is shown. Additionally the maturity of the main vehicle technology used and the existence or the compatibility with current infrastructure is reported.

Table 1: Reduction potentials of different fuels

Fuel	Reduction of petroleum dependence	Reduction of import dependence	Reduction of GHG emissions	Reduction of tailpipe pollutant emissions	Maturity of vehicle technology	Existence of infrastructure/ compatibility with current infrastructure
Petroleum based liquid fuels	-	-	-	-	3	3
Liquid biofuels	++	+[22]	++[23]	+	3	3
Methane	+++	+	+	+	3	1
LPG	+	-	+	+	3	2
Hydrogen	+++	+++	+++[24]	+++	0[25]	0
Electricity	+++	+++	+++[26]	+++	1	1

Note: For maturity and infrastructure availability 0 is the lowest value, representing the least maturity or infrastructure availability and 3 the highest.

Liquid biofuels can substitute oil based fuels and reduce emissions; the maturity of the vehicle technology is high as they are the same vehicles using oil fuels and the oil infrastructure can be converted to adapt to biofuels. The problem of import dependence will only be partly solved because if high amounts of biofuels enter the market EU production will not be sufficient to cover the demand. For accounting the use of biofuels, they are considered as zero CO_2 emissions fuel in transport sector, nonetheless emissions occur during their production and evidence is increasing that substantial emissions occur due to indirect land use (ILUC) (Croezen, et al. 2010), (Zanchi, Pena and Bird 2010).

Table 2: Correspondence of transport modes, vehicle technologies and fuels in PRIMES-TREMOVE Transport model

			Buses	Two wheelers	Passenger cars	Light duty vehicles	Heavy duty vehicles	Rail	Navigation	Aviation
Liquid Fuels	Gasoline blend	ICE		x	x	x			x	
	Ethanol	ICE			x					
	Diesel Blend	ICE	x		x	x	x	x	x	
	DME	ICE	x		x	x	x	x	x	
	B100	ICE	x		x	x	x	x	x	

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[22] Depending on the amount of biofuels that can be produced in the EU

[23] Subject to the consideration of indirect land use

[24] Depending on the power generation mix used to carry out the electrolysis

[25] The low maturity is due to the fact that currently fuel cell vehicles have costs of around €80000.

[26] Depending on the power generation mix

	Fuel oil blend	ICE							x	
	Jet fuel	Turbines								x
Gaseous Fuels	Natural gas /hydrogen blend	ICE	x		x	x	x		x	
	Natural gas/biogas blend	ICE	x		x	x	x		x	
	Biogas	ICE	x		x	x	x		x	
	LPG	ICE	x		x	x	x			
Fuel cells		H2FC EV	x		x	x	x			
Electricity		BEV	x	x	x	x	x			
		PHEV			x	x				
		On-grid						x		

Methane is able to decrease emissions and dependence on oil, but does not solve the problem of import dependence; the use of biogas could lessen the dependence. Natural gas reduces emissions compared to oil based liquids, but will not allow decarbonisation of the transport sector, unless biogas is used. Contrary to liquid biofuels, biogas is generally produced from waste products and therefore ILUC emissions cannot be directly attributed to biogas; the potential of waste is however limited.

The gas grid is available in most parts of the EU, but the refuelling infrastructure needs to be enhanced if the use of methane is to increase. While reducing tailpipe pollutant emissions and tailpipe GHG emissions in a similar way to natural gas, LPG does not substitute petroleum; it only allows for a more complete use of refinery products.

The import dependence also does not improve as its production is linked to the production of oil based fuels. LPG distribution infrastructure is available as LPG also has other uses; nonetheless as is the case for methane the refuelling infrastructure would need to be strengthened for increased use of LPG in transport.

Hydrogen allows for complete independence from petroleum and from imported energy (depending on how the electricity for electrolysis is produced); it allows for the elimination of all noxious tailpipe emissions and allows for the elimination of most WTW emissions if the power generation system is decarbonised. The infrastructure for hydrogen is currently non-existent and would need to be built up entirely. Electricity similarly to hydrogen can provide complete decarbonisation if the power generation sector is decarbonised and the elimination of all tailpipe emissions, as well as import independence. The main grid already exists, but would need to be strengthened and the recharging infrastructure would need to be built.

The fuels, including blends, and technologies as available in the model can be seen in Figure 4. They are classified by fuel form, by fuel type from a consumer perspective, by fuel type by supplier perspective and by vehicle technology. Additionally to the technologies mentioned there are the hybrid technologies including: conventional hybrids, plug-in hybrids and range extender vehicles.

These options are valid both for road and for non-road transport, although some options may not be available for all modes both for road and non-road. E.g. motorcycles with fuel cells are not contemplated as options, and aviation will remain based on turbine technology.

Table 3 shows the allocation of various alternative fuels to different transport modes according to the Report of the European Expert Group on Future Transport Fuels; different options about fuel and technology combinations for the various transport modes by time horizon are depicted.

Figure 4: Classification of fuels and technologies as represented in the model

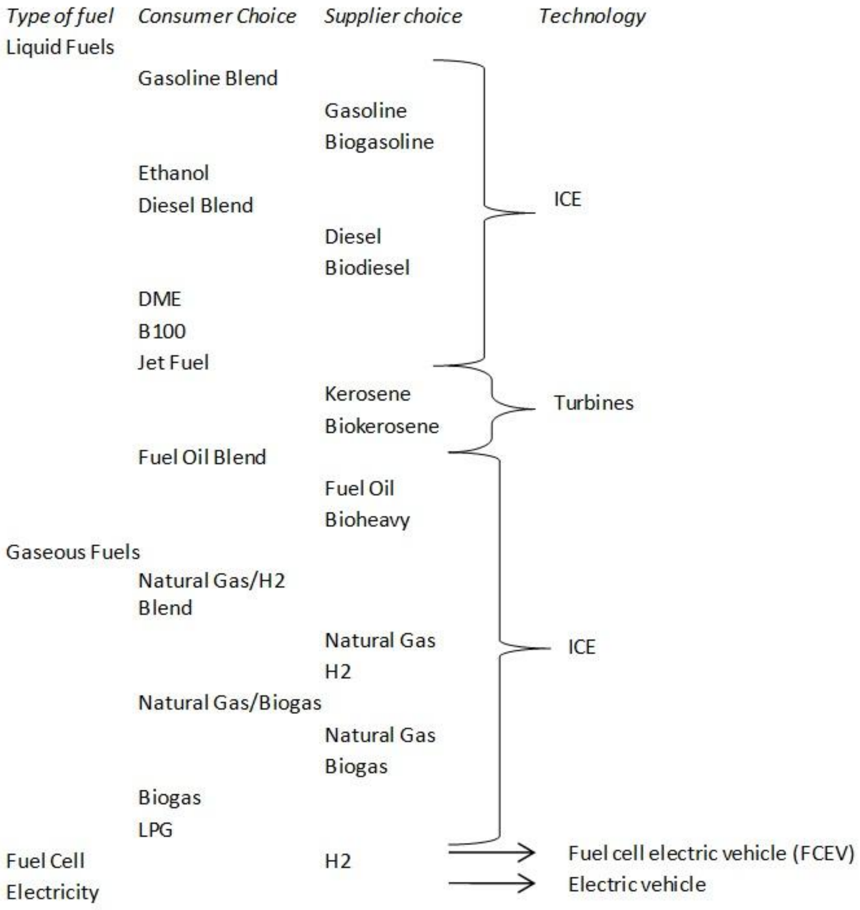
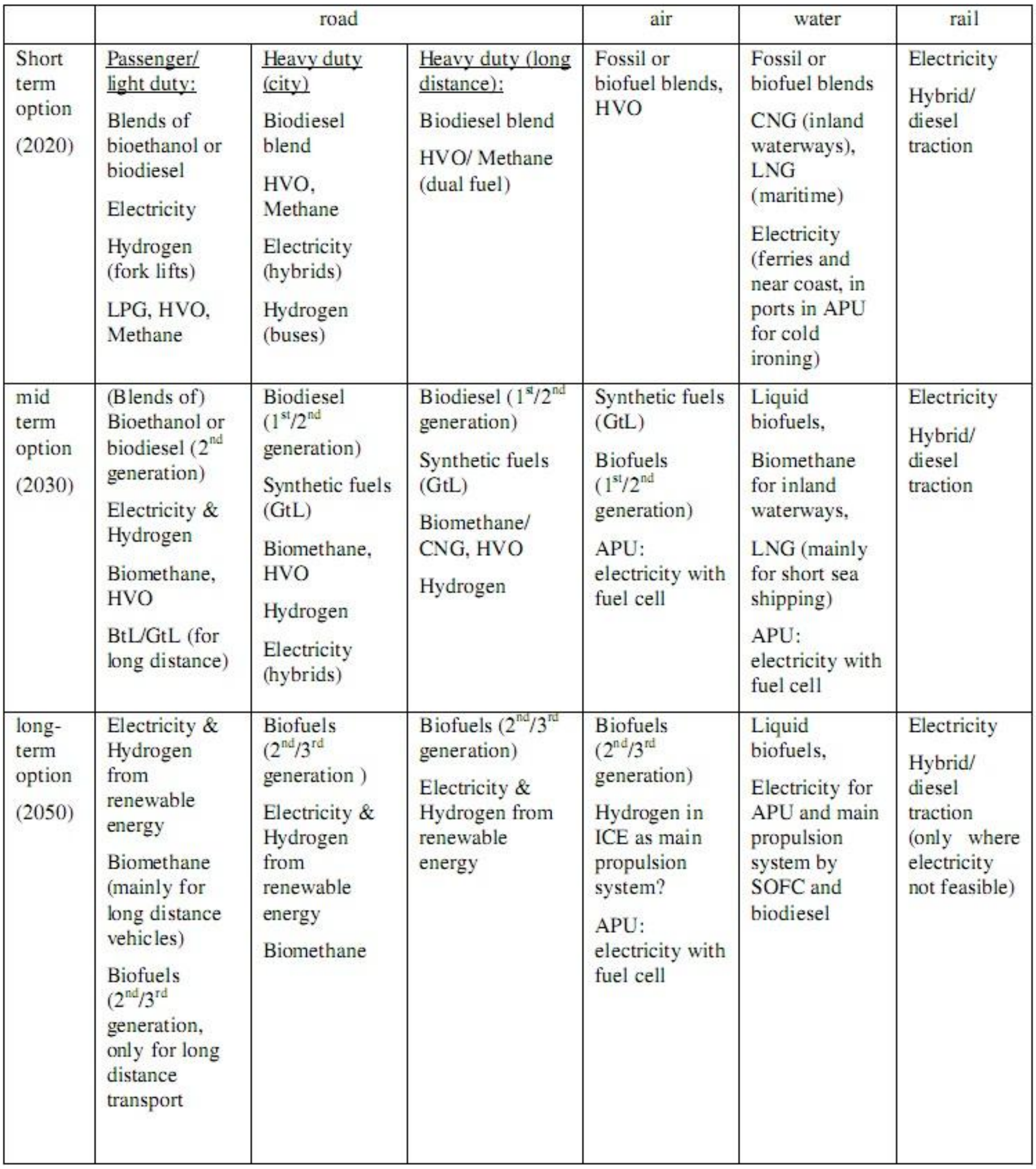


Table 3: Alternative allocation of fuels to different transport modes according to Joint Expert Group



	road			air	water	rail
Short term option (2020)	Passenger/ light duty: Blends of bioethanol or biodiesel Electricity Hydrogen (fork lifts) LPG, HVO, Methane	Heavy duty (city) Biodiesel blend HVO, Methane Electricity (hybrids) Hydrogen (buses)	Heavy duty (long distance): Biodiesel blend HVO/ Methane (dual fuel)	Fossil or biofuel blends, HVO	Fossil or biofuel blends CNG (inland waterways), LNG (maritime) Electricity (ferries and near coast, in ports in APU for cold ironing)	Electricity Hybrid/ diesel traction
mid term option (2030)	(Blends of) Bioethanol or biodiesel (2^{nd} generation) Electricity & Hydrogen Biomethane, HVO BtL/GtL (for long distance)	Biodiesel ($1^{st}/2^{nd}$ generation) Synthetic fuels (GtL) Biomethane, HVO Hydrogen Electricity (hybrids)	Biodiesel ($1^{st}/2^{nd}$ generation) Synthetic fuels (GtL) Biomethane/ CNG, HVO Hydrogen	Synthetic fuels (GtL) Biofuels ($1^{st}/2^{nd}$ generation) APU: electricity with fuel cell	Liquid biofuels, Biomethane for inland waterways, LNG (mainly for short sea shipping) APU: electricity with fuel cell	Electricity Hybrid/ diesel traction
long-term option (2050)	Electricity & Hydrogen from renewable energy Biomethane (mainly for long distance vehicles) Biofuels ($2^{nd}/3^{rd}$ generation, only for long distance transport	Biofuels ($2^{nd}/3^{rd}$ generation) Electricity & Hydrogen from renewable energy Biomethane	Biofuels ($2^{nd}/3^{rd}$ generation) Electricity & Hydrogen from renewable energy	Biofuels ($2^{nd}/3^{rd}$ generation) Hydrogen in ICE as main propulsion system? APU: electricity with fuel cell	Liquid biofuels, Electricity for APU and main propulsion system by SOFC and biodiesel	Electricity Hybrid/ diesel traction (only where electricity not feasible)

4 Context of the modelling exercise

This section describes the energy system context of the modelling exercise for the transport sector. The projection to the future of the overall energy system of the EU is performed for a Reference scenario and for a main decarbonisation scenario. The quantification was carried out using the PRIMES model. The section concludes with a general description of the cases quantified and analysed within this study and a description of the policies assumed.

4.1 Reference scenario

The Reference scenario for this project corresponds to the Reference scenario to 2050 endorsed by DG CLIMA[27], DG MOVE[28] and DG ENER[29] for the 2050 roadmap studies. In the following some of the details will be explained, with particular focus on those relevant to the transport sector. The Reference scenario assumes implementation of the 20-20 energy and climate policies and also the implementation of a series of Directives on energy efficiency. It is assumed that all EU policies adopted until March 2010 are successfully implemented but no new policies will be put in place. For the period beyond 2020, the projection includes effects from the policies adopted up to March 2010, as for example the ETS (which involves a linear reduction of allowances beyond 2020) and the efficiency directives.

Table **4**: Reduction of emissions in 2050 compared to 1990 and share of emissions by sector in 2050	**Percentage change compared to 1990**	**Share of Total Emissions**
Power generation/District heating	-69.2	18.8
Energy Branch	-44.9	3.5
Industry	-47.1	17.1
Residential	-39.7	12.4
Tertiary	-46.9	6.6
Transport	24.2	41.6
Total all sectors	-39.9	100.0
	1990	**2050**
Total CO2 emissions (MtCO2)	4031	2424

The Reference Scenario delivers the following reductions of GHG emissions domestically in the EU: 2020: - 22% from 1990; 2030: 29% from 1990; 2050: 39% from 1990.

In this scenario all sectors contribute extensively to the CO_2 emission reductions with the exception of the transport sector that reduces emissions by about 4% compared to 2005 and

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[27] EuropeanCommission, A Roadmap for moving to a competitive low carbon economy in 2050 (2011)

[28] EuropeanCommission, WHITE PAPER- Roadmap to a Single European Transport Area - Towards a competitive and resource (2011)

[29] Forthcoming report

therefore obtains a share of 41.6% of overall emissions by 2050. The reductions in every sector and their shares in 2050 can be seen in Table 4.

4.1.1 World fossil fuel prices

In the PRIMES model the average import prices for fossil fuels are exogenous; they are calculated with the Prometheus stochastic world energy model. The main influencing factors for fossil fuel prices are: development in world economic growth, car ownership and fossil fuel reserves (discovered and undiscovered).

The model takes into account the developments in world economic growth differentiated by regions but it is assumed on average not to exceed 3% between 2020 and 2030 (following IEA World Energy Outlook projections) and to be 2.2% per year in the years 2030 to 2050. Car ownership is assumed to grow in emerging economies, while in OECD countries it is assumed that it has already reached saturation. The amount of undiscovered reserves of oil and gas is uncertain. Undiscovered conventional oil is currently assumed to be on average close to 750 billion barrels of oil, compared to 1350 of known reserves today. For gas it is assumed that 130 trillion cubic meters of gas will be discovered until 2050, compared to 170 trillion cubic meters of gas reserves known today[30].

According to the model-based projection, world primary energy requirements will continue to grow and will double by 2050 from today's level. Fossil fuels will continue to dominate the energy balance and coal use is likely to expand noticeably over the entire period. Renewables and nuclear are projected to increase at a pace higher than average but their contribution in share terms is projected to remain low at a global level.

Based on the above analysis the following price assumptions are used:

Table 5: Fossil fuel prices assumptions

	Fossil fuel prices as imported to the EU($2008)		
	Oil	Gas (GCV)	Coal
	US$/bbl	US$/MMBTU	US$/t
2000	35.5	4.1	42.4
2005	59.4	6.5	67.4
2009	48.6	6.3	77.0
2010	71.9	7.2	82.7
2020	88.4	10.1	123.9
2030	105.9	12.5	140.9
2040	116.2	14.2	140.9
2050	126.8	16.1	144.8

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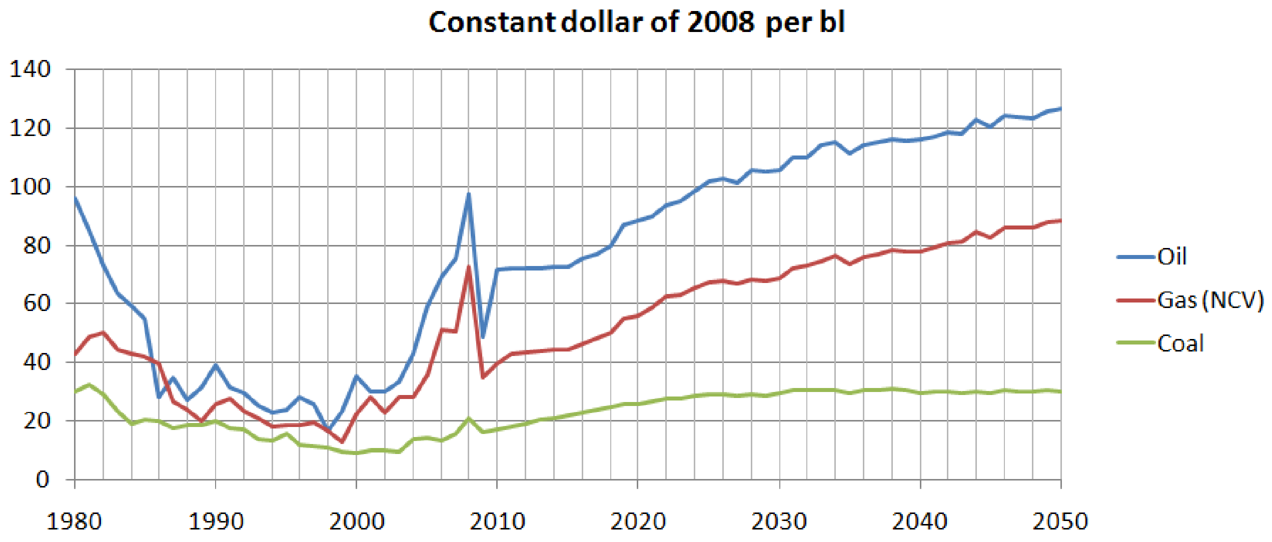
[30] This volume of gas includes tight gas and coal-bed gas of the type exploited today in North America but not unconventional gas, such as hydrates.
The use of shale gas is causing changes to the gas market; this has caused changes in particular in the US market and a consequent decrease in LNG prices. Nonetheless the influence on the European market has been limited. For this reason and to ensure consistency with the Reference and Baseline scenarios prepared for DG ENER we will maintain the same assumptions.

In the short-run the projection shows that crude oil productive capacity expansion is slowed down or deferred as a result of low prices and depressed demand due to the recession of the global economy. It is then projected that during the recovery period oil and gas demand growth begins to accelerate and, capacity pressures are likely to drive oil and gas prices upwards. As a result, oil prices could exceed 80 $/bbl (in constant money of 2008) before 2020. The resource constraints and the sustained growth of demand is projected to drive prices even higher, leading to oil prices higher than 100 $'2008/bbl by 2030 and beyond. According to the model results, the probability that oil prices remain below 80 $/bbl is less than 30% over the entire period, after the recession period. There are more than 50% chances that oil prices will average more than 100 $/bbl after 2030.

Figure 5: International fuel prices



4.1.2 Technologies

All current technologies continue existing in the Reference scenario and follow a line of modest efficiency improvement. No technology breakthroughs are considered to occur, therefore improvements in innovative technologies such as batteries or fuel cells do not occur. For passenger cars, two wheelers and light duty vehicles the EURO standards up to EURO VI are introduced.

For non-road transport, rail, navigation and aviation, modest efficiency improvements occur throughout the projection period.

4.1.3 Infrastructure development

No major changes in the energy infrastructure are assumed in the Reference scenario.; the currently existing infrastructure is expected to be renovated over time.

4.1.4 Policy drivers

The policies implemented in the transport sector, within the Reference scenario, and included in the model are those adopted up to March 2010 and are presented in Table 6.

Table 6: Policies implemented in the transport sector, within the Reference scenario

	Policy measure	How the measure is reflected
1	Regulation on CO2 from cars 2009/443/EC	Limits on emissions from new cars: 135 gCO_2/km in 2015, 115 in 2020, 95 in 2025 – in test cycle. The 2015 target is achieved gradually with a compliance of 65% of the fleet in 2012, 75% in 2013, 80% in 2014 and finally 100% in 2015. Penalties for non-compliance are dependent on the number of grams until 2018; starting in 2019 the maximum penalty is charged from the first gram.
2	Regulation EURO 5 and 6 2007/715/EC	Emission limits introduced for new cars and light commercial vehicles.
3	Fuel Quality Directive 2009/30/EC	Modelling parameters reflect the Directive, taking into account the uncertainty related to the scope of the Directive addressing also parts of the energy chain outside the area of PRIMES modelling (e.g. oil production outside EU).
4	Biofuels directive 2003/30/EC	Support to biofuels such as tax exemptions and obligation to blend fuels is reflected in the model. The requirement of 5.75% of all transportation fuels to be replaced with biofuels by 2010 has not been imposed as the target is indicative. Support to biofuels is assumed to continue. The biofuel blend is assumed to be available on the supply side.
5	Implementation of MARPOL Convention ANNEX VI - 2008 amendments - revised Annex VI	Amendment of Annex VI of the MARPOL Convention: reduce sulphur content in marine fuels which is reflected in the model by a change in refineries output.
6	Labelling regulation for tyres 2009/1222/EC	Decrease of perceived costs by consumers due to labelling (which reflects transparency and the effectiveness of price signals for consumer decisions).
7	Regulation Euro VI for heavy duty vehicles 2009/595/EC	Emissions limits introduced for new heavy duty vehicles.
8	RES directive 2009/28/EC	Legally binding national targets for RES share in gross final energy consumption are achieved in 2020; 10% target for RES in transport is achieved for EU27, as biofuels can easily be traded among Member States; sustainability criteria for biomass and biofuels are respected; cooperation mechanisms according to the RES directive are allowed and respect Member States indications on their "seller" or "buyer" positions.
9	EU ETS directive	Inclusion of aviation in EU ETS starting with 2012

	2009/29/EC	
10	Energy Taxation Directive 2003/96/EC	Tax rates (EU minimal rates or higher national ones) are kept constant in real term. The modelling reflects the practice of Member States to increase tax rates above the minimum rate due to i.e. inflation.
11	Regulation on CO2 from vans (part of the Integrated Approach to reduce CO2 emissions from cars and light commercial vehicles)[31].	Limits on emissions from new LDV: 181 gCO2/km in 2012, 175 in 2016, 135 in 2025 – in test cycle
12	Directive on national emissions' ceilings for certain pollutants 2001/81/EC	Checked with RAINS/GAINS modelling regarding classical pollutants (SO2, NOx)
13	GHG Effort Sharing Decision 406/2009/EC	National targets for non-ETS sectors are achieved in 2020, taking full account of the flexibility provisions such as transfers between Member States. After 2020, stability of the provided policy impulse but no strengthening of targets is assumed.
14	Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles 2009/33/EC	Emission factors, impact on costs per km
15	Eurovignette Directive on road infrastructure charging 2006/38/EC	No additional link based charges. Assumed current level of internalisation through fuel taxes and existing infrastructure charges (tolls or vignettes) where applicable
16	TEN-T guidelines 884/2004/EC	Priority projects introduced in TRANSTOOLS network according to expected completion date
17	Emission standards for diesel trains (UIC Stage IIIA)	Emission factors, impact on costs per km
18	ICAO Chapters 3 (emissions)	NO_x and CO emission standards for airplanes built after 2007. Updated emission factors from EXTREMIS database (http://www.ex-tremis.eu) applied on TRANSTOOLS demand projections
19	Single European Sky II	Decrease in fuel consumption, emissions and ticket prices

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[31] Due to the time of the finalisation of the Reference scenario, the Regulation on CO2 from vans is modelled following the European Commission proposal of 28 October 2009 which differs to some extent from the Regulation recently adopted by the European Parliament and the Council (Regulation (EU) No 510/2011 of the European Parliament and of the Council of 11 May 2011, setting emission performance standards for new light commercial vehicles as part of the Union's integrated approach to reduce CO2 emissions from light-duty vehicles).

	COM(2008) 389 final	
20	Directive on inland transport of dangerous goods 2008/68/EC	No significant impact
21	Third railway package 2007/58/EC	Assumed discount on user prices and decrease in rail passenger costs after 2010
22	Port state control Directive 2009/16/EC	Decrease in transhipment costs
23	Regulation on common rules for access to the international road haulage market Regulation No 1072/2009	More efficient international road freight transport (reduced empty returns) reflected through a decrease in international transport costs
24	Directive concerning social legislation relating to road transport activities 2009/5/EC	Exclusion of self-employed drivers from the working time directive, simplification of the tachograph rules, use of targeted electronic controls; reflected through a decrease in inter-urban road transport

No further policies are implemented aside from these policies. The carbon value[32] (which applies to non-ETS sectors) is assumed to remain constant after 2020 at 5.3€/tCO_2; aviation is included in the ETS starting with 2012.

The average fuel prices for the EU excluding VAT can be seen in Table 7.

Table 7: Fuel prices excl. VAT

	Fuel prices excl. carbon price effects				
(Euro/toe)	2005	2020	2030	2040	2050
Gasoline (incl. ethanol)	1209	1549	1727	1866	2018
Diesel (incl.B100,DME)	1002	1303	1489	1634	1790
methane(incl. biogas)	741	883	1043	1175	1331
LPG	687	919	1120	1258	1406
Liquefied hydrogen	2977	2977	2877	2678	2707
Electricity	1460	1902	1994	1927	1936

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[32] Carbon value is a common modelling tool which is used with the scope of shifting to more efficient and carbon-free technologies by penalising the carbon-intensive ones; it does not imply additional cost to the system.

	Fuel prices incl. carbon price effects				
(Euro/toe)	2005	2020	2030	2040	2050
Gasoline (incl. ethanol)	1209	1564	1742	1881	2033
Diesel (incl.B100,DME)	1002	1319	1505	1650	1805
methane(incl. Biogas)	741	897	1057	1189	1345
LPG	687	935	1136	1274	1422
Liquefied hydrogen	2977	2977	2877	2678	2707
Electricity	1460	1902	1994	1927	1936

4.1.5 Main results for the Reference scenario

According to the Reference scenario projection, transport will remain highly liquid petroleum dependent over the projection period; however a slight decline of oil products consumption is observed in absolute terms in 2050 compared to 2005. Renewable energies in transport reach 13.3% of gross final energy consumption: biofuels represent 10% of liquid fuel consumption and do not penetrate the aviation sector or non-road transportation. Both passenger and freight rail are further electrified over the time period under consideration; for passenger rail diesel consumption represents about 3% of total energy consumption by 2040; whereas for freight rail the percentage is slightly higher, at 8.5% in 2040 and decreasing to around 3% by 2050. [33] The CO_2 and cars Regulation drives towards non –oil technologies such as biofuels and electricity, which appear in the scenario, but it is not sufficient to reduce the share of oil considerably or achieve decarbonisation.[34]

Activity

Activity in the Reference scenario rises throughout the projection period both for passenger and freight transport. The shares in activity within the transport sector change very little between 2005 and 2050 in the Reference scenario. In passenger transport the only noticeable increase takes place in aviation, which increases from 8% to about 15% of total passenger activity; passenger cars represent about 67% in 2050 corresponding to a decrease of 6 percentage points in modal share by 2050 compared to 2005.. Freight transport increases by slightly less than 1% per year between 2005 and 2050; the increase is almost equally distributed among the sectors, with a slightly slower increase in inland navigation compared to rail and road transport.

Table 8: Activity in the transport sector

(Gpkm)	1990	2005	2010	2020	2030	2050	Average annual percentage change		
							1991-2010	2011-2030	2031-2050
PASSENGER TRANSPORT	**4881**	**6240**	**7125**	**7555**	**8386**	**9453**	**1.9%**	**0.8%**	**0.6%**
Public road transport	544	526	574	601	642	687	0.3%	0.6%	0.3%
Private road transport	3366	4536	5123	5355	5806	6003	2.1%	0.6%	0.2%
2wheelers	135	150	166	178	197	219	1.0%	0.9%	0.5%

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[33] The electrification of rail is an assumption that has been taken and has been agreed upon by Member States; the change implies that additional policies will take place. To ensure compliance with the Reference and Baseline scenarios prepared for DG ENER the assumption has been maintained throughout the scenarios quantified in this project.

[34] Regarding navigation, the PRIMES-TREMOVE model only covers inland navigation. Issues relating to bunkers and therefore international maritime navigation are covered in the overall PRIMES model.

Rail	472	461	523	565	642	767	0.5%	1.0%	0.9%
Aviation	317	527	697	814	1053	1388	4.0%	2.1%	1.4%
Inland navigation	46	40	42	44	46	50	-0.4%	0.4%	0.4%

(Gtkm)	1990	2005	2010	2020	2030	2050	Average annual percentage change		
							1991-2010	2011-2030	2031-2050
FREIGHT TRANSPORT	**1848**	**2495**	**2958**	**3125**	**3438**	**3863**	**1.77%**	**0.75%**	**0.58%**
Trucks	1060	1800	2172	2285	2517	2840	3.65%	0.74%	0.61%
Rail	526	414	488	525	579	652	-0.38%	0.85%	0.60%
Inland navigation	262	280	298	315	342	370	0.66%	0.69%	0.40%

Final energy demand

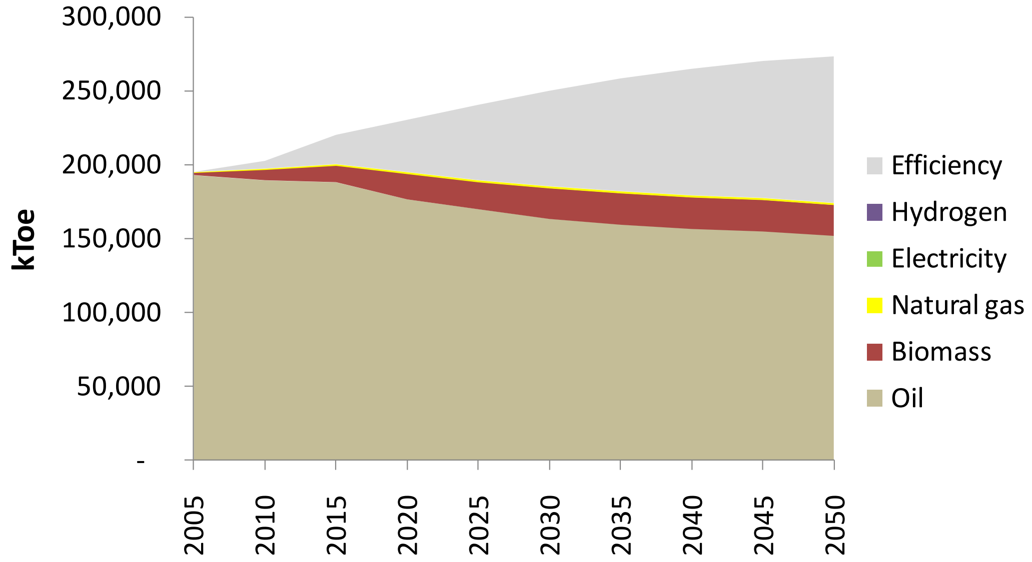
The final energy demand of the reference scenario peaks in 2020 after which energy efficiency gains are able to compensate for increased activity and in 2050 energy consumption is 6.8% higher than in 2005. Road transport energy consumption peaks in 2020 and then starts declining whereas non-road transport continues increasing steadily throughout the time period driven by a high increase in aviation, where energy consumption rises by 43% compared to 2005. Oil consumption in the scenario decreases from a share of 97% in 2005 to 87% in 2050.

Table 9: Composition of final energy demand by delivery form in the reference scenario

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Liquid Fuels	351	381	375	370	24	18
Gaseous Fuels	5	9	9	8	4	3
Liquefied hydrogen	0	0	0	0	0	0
Electricity	6	8	9	9	2	3
Total	**362**	**398**	**392**	**387**	**30**	**24**

As can be seen in Table 9 liquid fuels continue remaining the main energy form; the shares of gaseous fuels and electricity remain constant from 2020 at 2% each. An increase in electricity consumption can be observed which is due exclusively to the electrification of rail. The composition of liquid fuels remains similar to today's; up to 2020 there is an increase of biofuel share which then remains almost constant for the remaining part of the projection period.

Figure 6: Energy consumption of cars, LDV and 2wheelers incl. efficiency gains relative to 2005



Gaseous fuels make up only 2% of the total energy demand and the share remains almost as we know it today; gaseous fuels are dominated by LPG, but the share of natural gas increases up to 2020. Biogas shares remain negligible.

The biofuel mix is dominated entirely through biodiesel for blending throughout the projection period.

There are limited efficiency gains compared to 2005; the improvements are due to an increased use of hybrid technology, but the majority of new sales, approx. 65% is still due to conventional gasoline and diesel ICEs. These are assumed to improve limitedly over time. As can be seen in Figure 6, the energy consumption of private road transport decreases slightly over the project period compared to 2005; this is mainly due to hybridisation and improvements in conventional ICEs.

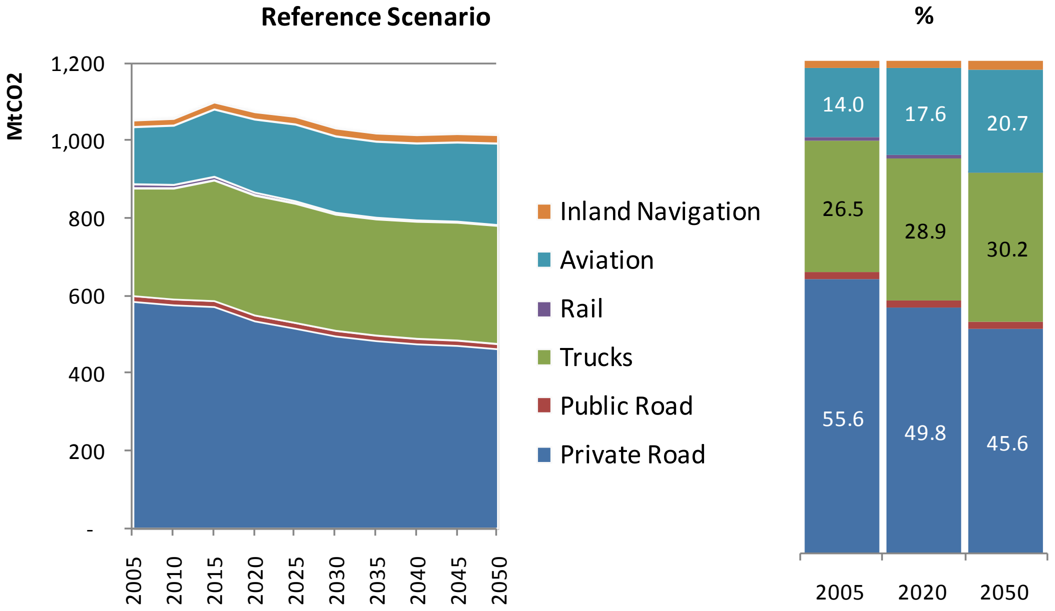
For HDVs energy consumption remains almost constant after 2020 due to improvements in efficiency and hybridisation.

For non-road transport energy consumption increases throughout the time period, driven by aviation, although aviation sees a large efficiency improvement driven by the fuel prices. Rail is almost entirely electrified and energy consumption remains almost stable as the increased efficiency of electric rail compensates for the increase in activity. For inland navigation, energy consumption increases throughout the time period.

CO_2 emissions

Emissions in 2050 are still about 24% higher than in 1990, but 4% lower than in 2005. The policies implemented up to 2020 have the effect of limiting a further increase of emissions along historical trends, but do not have the potential to decrease the emissions substantially. The highest emissions are due to private cars, followed by trucks and aviation (see Figure 7).

Figure 7: Total CO_2 emissions by transport mean



WTW emissions are 14% lower compared to 2005. Due to the limited changes in the overall energy system context the indirect CO_2 emissions remain proportional to the energy consumption over time.

4.2 Energy system context for the decarbonisation scenarios

4.2.1 Overview

The cases quantified for this study take place in the context of overall decarbonisation of the economy in the EU, with global climate action worldwide, assuming effective technology development and deployment; the overall energy system context has been determined using the overall PRIMES model. On a global level the action implies countries achieving their pledges proposed in the Copenhagen Accord of December 2009; for the EU the decarbonisation target assumed is a CO_2 emission domestic reduction of 80% compared to 1990. The macro-economic assumptions are assumed to remain constant between the reference and the policy cases, due to the changed policy context international fuel prices are strongly affected.

The international prices of fossil fuels are lower, than in reference case, in a context of global action on climate change, due to lower demand for fossil fuels worldwide. For the policy scenarios the price projections can be seen in Figure 8. Starting from 2015 the international fuel price costs start diverging from the Reference scenario and reach values that are 45%, 50% and 30% lower for oil, gas and coal respectively compared to the Reference scenario.

Figure 8: International fuel prices in the Reference and Decarbonisation scenario under global climate action

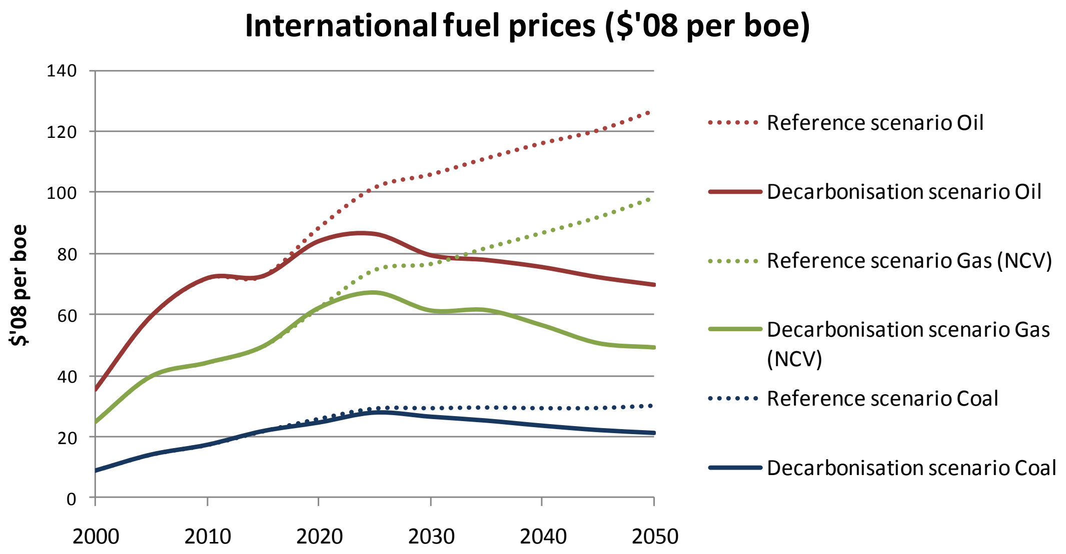
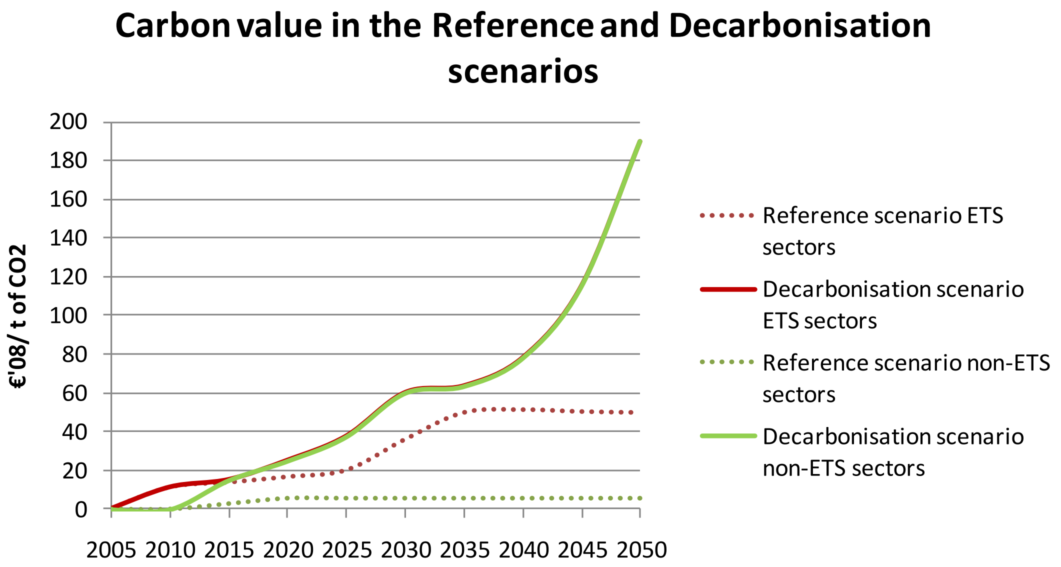


Figure 9: Carbon value in the Reference and decarbonisation scenarios



To achieve the target of decarbonisation in the context of lower fuel prices strong price signals are needed; these are given in the form of the carbon price for ETS and the carbon value[35] for non ETS. In the Reference scenario it is assumed that the carbon value for non-ETS sectors remains constant after 2020 at 5.3€/tCO_2[36], whereas the carbon price for the ETS sectors

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[35] A carbon value is a price signal influencing fuel mix and savings but is assumed not to entail payments for carbon, contrasting a carbon price which does entail carbon payments. A carbon value is used in the modelling as a shadow value associated to an overall (EU level) emission reduction constraint.

[36] This relatively low marginal cost for the non-ETS sector is due to: the inclusion of non-CO2 abatement options which to a certain extent allow emission reductions at relatively low costs; the assumption of renewables support policies for heating and transport and to additional energy efficiency policies reflected in the Reference scenario.

increases until 2035 and remains constant after 2035 at a level of roughly 50 €'08/tCO_2. This level of the ETS market clearing price reflects an assumption of a continuation of a linear decrease of ETS allowances until 2050.

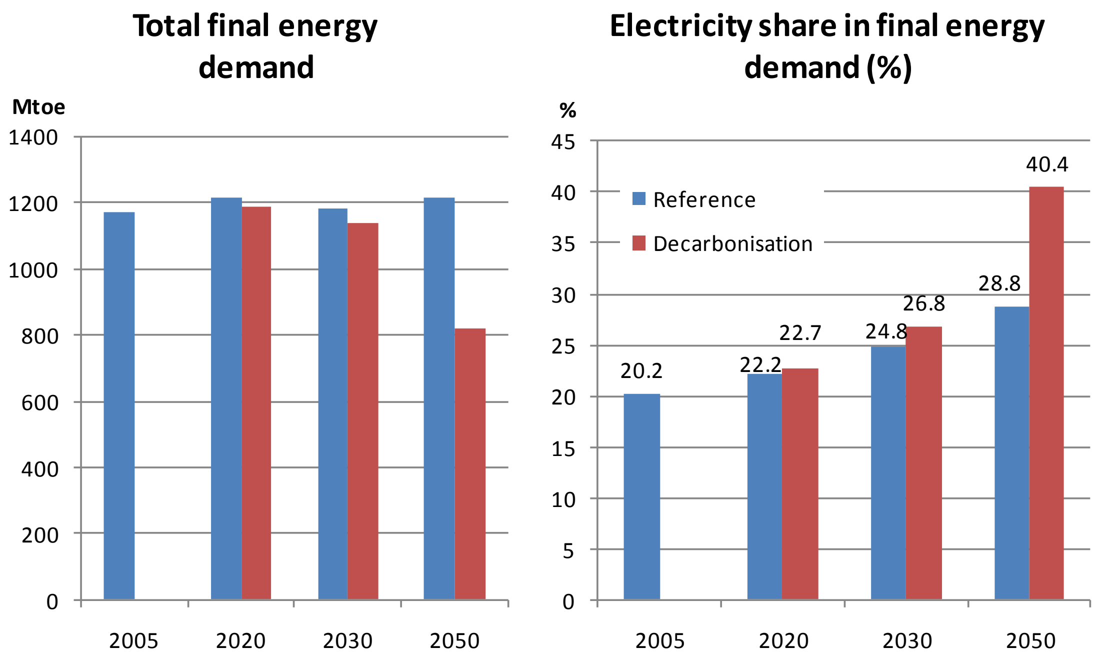
For the decarbonisation scenario it is assumed that the carbon price for the ETS sectors and the carbon value for non-ETS sectors have the same numerical value (see Figure 9) and are both higher than in the Reference scenario. This carbon value is obtained endogenously in PRIMES[37] to achieve the target of -80% CO_2 emissions in a context of global climate action and effective technology deployment. This scenario is used to quantify the contribution required from the transport sector in the overall decarbonisation effort.

4.2.2 Energy system results

The high carbon value induces the system to reduce final energy demand and to decarbonise in all sectors by increasing energy efficiency and the degree of electrification in all sectors.

Electricity being decarbonised ingeneration helps reducing emissions in final demand sectors by substituting for fossil fuels. This takes place in heating uses (through heat pumps and others) and in transportation (through electric cars). In case hydrogen deploys as a new carrier, it is also produced through an almost carbon free process, as for example from electrolysis which uses electricity produced by carbon free (or almost carbon free) sources.

Figure 10: Final energy demand and share of electricity in final energy demand



A major change in decarbonisation scenarios is the impressive improvement of energy efficiency in all sectors which has a major contribution to emission reduction. Energy savings

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[37] SEC(2011) 288 final, Impact Assessment of the "Roadmap for moving to a competitive low carbon economy in 2050".

reduce consumption of all energy forms and also reduce electricity demand in stationary uses. Electricity penetrates mobility uses (directly or via hydrogen) compensating part of electricity demand reduction in stationary uses.

Total demand for electricity is similar in the decarbonisation scenarios, compared to the reference case, but the composition in stationary and mobility uses differs.

As can be seen in Figure 10 final energy demand decreases by about 30% compared to 2005 levels, while it increases slightly in the Reference scenario. The share of electricity in final energy demand rises increasing to just above 40% in 2050.

Power generation sector

The power generation sector shifts away from fossil fuels mainly towards renewable energy sources and nuclear; the remaining fossil fuel power plants are almost entirely equipped with carbon capture and storage -CCS (97.4% net electricity generation from thermal fossil fuel fired power plants is generated from plants equipped with CCS). The share of renewable energy in net electricity generation reaches 51.4%, while representing 65.8% of installed net power capacity.

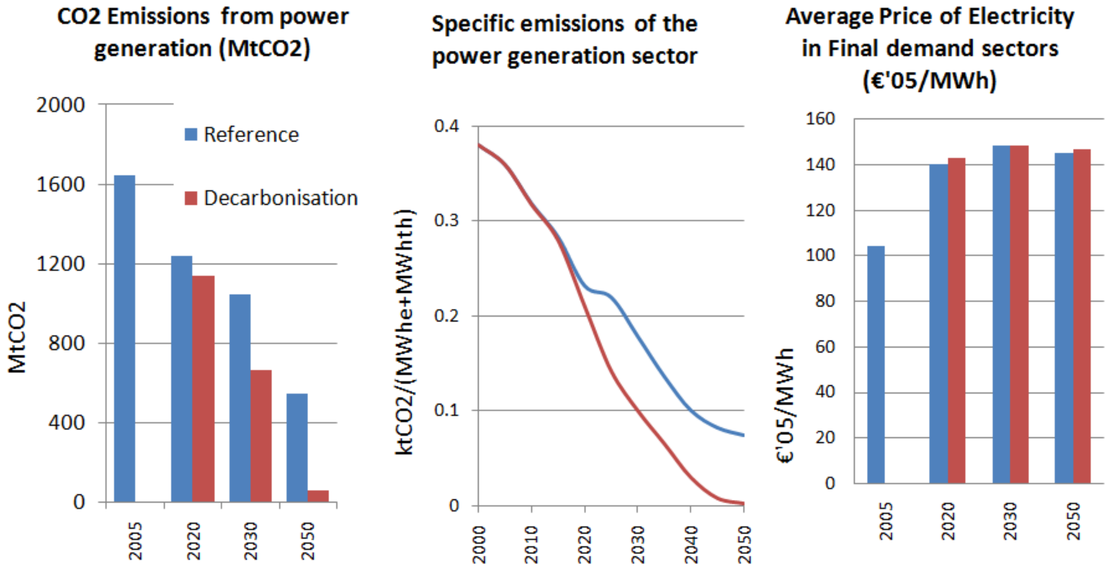
The emissions from the power generation sector are reduced by 96% in 2050 compared to the emissions in 2005. The specific emissions per generated electricity and steam decrease from 0.36ktCO$_2$/MWh in 2005 to almost zero in 2050 (see Figure 11).

The investments in the power generation sector in the decarbonisation scenario are about €600bln. higher than the Reference scenario. The additional investment costs only have limited effects on the average electricity price in the final demand sectors due to the lower fuel prices assumed in the decarbonisation scenario (see Figure 11).

Table 10: Electricity generation in the Reference and decarbonisation scenario

(TWh)	2005	2030		2050	
	Reference	Reference	Decarbon isation	Reference	Decarbon isation
Total	**3077**	**3975**	**3825**	**5324**	**4544**
Nuclear energy	945	1151	930	1407	1194
Hydro (pumping excluded)	301	351	350	368	365
Wind power	70	959	805	1456	968
Solar	1	176	125	437	237
Other renewables (tidal etc.)	0	9	8	19	12
Solids fired	903	279	589	443	564
Oil fired	123	45	61	4	110
Gas fired	649	667	649	736	749
Biomass-waste fired	79	329	300	443	336
Geothermal heat	5	9	8	12	9

Figure 11: Emissions from power generation and average electricity price



CO_2 Emissions

The high carbon price signals trigger the uptake of low or carbon free technologies in power generation and distributed steam sector, which are almost completely decarbonised by 2050, emitting only 24MtCO$_2$ in 2050. This represents a reduction of emissions of about 98% compared to 1990. Figure 12 shows the CO$_2$ emission pathways for the Reference and decarbonisation scenarios both overall and for the transport sector. The share of CO2 emissions from transport would continue increasing by 2050, following a relatively lower decline of CO2 emissions from transport compared to power generation and other sectors.

The results of the PRIMES Effective and widely accepted technology scenario[38] show that transport-related emissions of GHG should be reduced by around 60% by 2050 compared to 1990 in order to achieve a reduction of GHG emissions that is consistent with the long-term requirements for limiting climate change to 2 °C and with the overall target for the EU of reducing domestic emissions by 80% by 2050 compared to 1990. All scenario cases, except the Reference scenario, quantified for this CTS study achieve around 60% CO$_2$ emission reductions compared to 1990 for the transport sector.

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[38] SEC(2011) 288 final, Impact Assessment of the "Roadmap for moving to a competitive low carbon economy in 2050".

Figure 12: Total and transport sector CO_2 emissions in the Reference and Decarbonisation scenarios

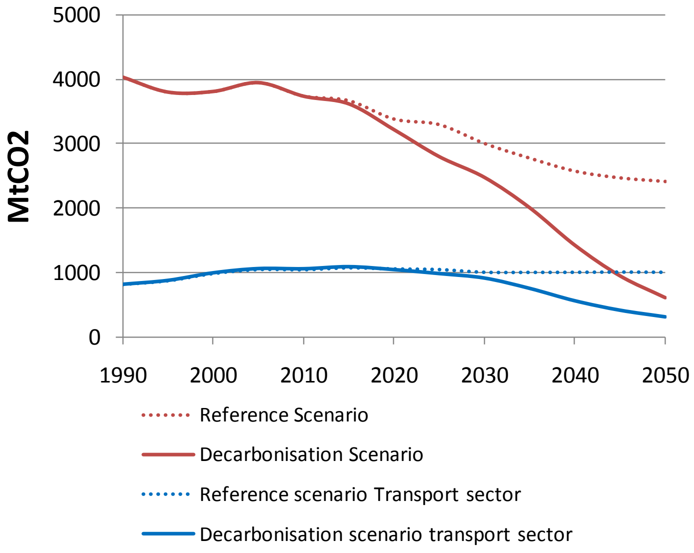

Table 11: CO_2 emissions in 1990 and in 2050 for the Reference and Decarbonisation scenarios per sector

	1990	2050	
		Reference	Decarbonisation
Total Emissions (MtCO2)	**4031**	**2423**	**614**
Power and Distr. Steam	1484	457	24
Energy Branch	152	84	27
Industry	781	414	151
Residential	499	299	61
Tertiary	301	160	36
Transport	813	1009	313

Natural gas

In the scenarios two natural gas blends are considered: natural gas with hydrogen and natural gas with biogas.

Natural gas of fossil origin is assumed to be blended with hydrogen starting from 2035; this allows reducing the emissions of gas consumed within the EU, but increases the price of gas for consumers. By 2050 the share of hydrogen in the natural gas blend achieves values up to 30% in the EU, depending on the scenario. The hydrogen produced in the PRIMES model is produced from electrolysis which implies that the emissions of hydrogen are dependent on the power generation emissions that reduce over time; by 2050 hydrogen can be considered an almost carbon free energy carrier.

The blending with biogas occurs throughout the time period considered, with rising shares over time, which however are kept below 5%. The exact amount of biogas in the blend depends on the specific scenario assumptions.

Biomass

The PRIMES model includes a biomass sub-model that simulated the production of bio-energy commodities of various kinds which are used in final demand sectors, in power generation and in heat/steam production as projected by the overall PRIMES model; the biomass supply sub-model determines the optimal diffusion of biomass and waste conversion technologies, the necessary feedstock, the arable land used and the costs and prices of the bio-energy commodities.

Feedstock is classified into crops (e.g. wheat or ligno-cellulosic crops); agricultural residues; forestry products; waste (e.g solid waste) and black liquor. Biomass can be either produced/cultivated domestically in the EU or can be imported; imports can be either in the forms of feedstock (e.g. solid biomass) or as ready to use fuels (e.g. biodiesel). A large variety of processes are used to convert the primary biomass into fuels such as fermentation, esterification, FT-synthesis and others. Through these processes the PRIMES-Biomass supply model simulates the production of a number of biomass based fuels of which those relevant for transport are:

- Biodiesel;
- Biokerosene;
- Ethanol;
- BioHeavy; and
- BioGas.

The amount of land used for biofuel production in the EU rises 7-fold from 2005 to 2050, with the greatest increase accounted for by lignocellulosic biomass which can be cultivated on land previously not used for food crops. The amount of land used for the production of starch, oil and sugar crops increases between 2010 and 2020 and then starts decreasing again as 2nd generation biofuel technologies develop, which require lignocellulosic feedstock, instead of feedstock that competes with food crops.

As in all PRIMES models the technologies are assumed to improve over time; the speed of the improvement depends on economies of scale, therefore the extent of deployment of a specific technology, and on assumed R&D developments. The improvements increase the output of fuel and/or increase the efficiency of the process. Over time different processes for the production of the same fuel become available, e.g. second generation technologies. In the scenarios analysed here second generation biofuels become largely available after 2020; although 3rd generation biofuels are available as technology in the model, these are only used when large amounts of biofuels are required for the transport system and under the assumption that the cost associated to the technology will decrease substantially.

The use of the biomass model allows verifying that the biomass demanded by the transport model can be produced domestically or with the help of imports; this allows to limit the use of biofuels within boundaries that are expected to maintain sustainability of biomass production.

4.2.3 Conclusions

For the transport sector there are potentially two energy carriers that become almost carbon free by the end of the time period considered: electricity and hydrogen. Additionally biofuels can be used that are considered as carbon neutral sources according to Eurostat. The share of biofuels is determined endogenously in the PRIMES model based on policies for biofuels blends and the relationship between the biofuel production prices (determined in the PRIMES biomass supply model), the international fuel prices and the policy context (taxation of fuels, targets, etc.).

The cases quantified for this project are developed in the context of the overall PRIMES decarbonisation scenario under effective technology and global climate action where the transport sector is expected to contribute by achieving approx. 60% emissions reduction, in line with the White Paper aim.

5 Transport sector scenario-cases developed for the CTS study

5.1 Definition of scenarios quantified using PRIMES-TREMOVE Transport model

The scenario-cases quantified and analysed within the CTS study were developed taking as starting point the analysis included in the impact assessment report accompanying the White Paper "Roadmap to a Single Transport Area – Towards a competitive and resource efficient transport system"[39], adopted in March 2011. The aim of quantifying alternative scenarios within the CTS study was to quantify the contributions of different fuel and technology combinations for the various transport modes (e.g. road, freight, etc.) and different options about fuel and technology combinations over the time horizon (e.g. medium-term vs. Long-term horizon) to achieve the main objective of the White Paper.

The PRIMES-TREMOVE model relates different fuel-technology combinations with specific drivers such as technology success (e.g. batteries, fuel cells), availability of new fuels (e.g. hydrogen, grid electricity, methane fuels), the density of refuelling and recharging infrastructure and regulation based on CO_2 emissions or energy efficiency standards.

In this study ten scenario-cases were quantified and analysed, which were defined as resulting from combination of assumptions regarding the following topics:

- Battery technology development (battery costs, vehicle range);
- Fuel cell stack and system costs reduction;
- Market potential of biofuels;
- Alternative developments of multiple refuelling infrastructures;
- Alternative regulation schemes, as for example CO_2 versus energy efficiency standards.

The different combinations were firstly grouped in three main scenario-cases, which contrast with each other:

- **Dominant Electricity**: this case is characterised by a strong development of electro-mobility and the related infrastructure. The electro-mobility case is further distinguished into two variants:
    - Strong competitive advantage of vehicle technologies based on batteries further referred to as “Battery Success” case, and
    - Additionally to the battery success, great improvement in costs and performance of fuel cell technology further referred to as “Fuel Cell Success” case.
- **Dominant Biomass**: this case assumes success with production and market diffusion of new generation biofuels, combined with substantial improvement of internal combustion

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[39] COM(2011) 144

engines; the diffusion is facilitated by development of multiple fuel infrastructure and by technology progress allowing for high efficiency gains in conventional vehicle technologies, mainly ICEs; this case assumes only a moderate success in electro-mobility, which combines with a moderate market penetration of electric vehicles.

- **"Renew"**: this case is a combination of the above two cases which assumes successful development of both options, namely electro-mobility and the new biomass-based fuels; this cases assumes high development of multiple fuel and recharging infrastructures. Regarding the electro-mobility market segment, this case is further distinguished into two cases, namely one with higher success in battery driven vehicles and one with higher success in fuel cells.

Table 12: Characteristics of the cases developed within the CTS project

Scenario	Dominant Electricity				Dominant Biomass		Renew			
	A / CO2	A / EFF	B / CO2	B / EFF	CO2	EFF	A / CO2	A / EFF	B / CO2	B / EFF
Technological development (range, costs) for battery electric vehicles	High	High	High	High	Moderate	Moderate	High	High	High	High
Technological development (range, costs) for fuel cell vehicles	High	High	Moderate	Moderate	Moderate	Moderate	High	High	Moderate	Moderate
Supply and availability of biofuels, biogas, etc	Low	Low	Low	Low	High	High	Moderate	Moderate	Moderate	Moderate
Refuelling infrastructure (multiple or focused)	Focused	Focused	Focused	Focused	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple
Main Policy Driver (CO2 regulation, Energy Efficiency regulation)	CO_2	Efficiency	CO_2	Efficiency	CO_2	Efficiency	CO_2	Efficiency	CO_2	Efficiency

Each of the resulting five cases (two cases for dominant electricity, one case for dominant biomass and two cases for "RENEW" scenario) were analysed under both CO_2 emission standards and energy efficiency standards. Therefore altogether ten different scenario-cases were quantified, the main elements of which are summarised in Table 12.

5.2 Common Policies for the CTS cases

The PRIMES-TREMOVE model is able to represent a large variety of policies and measures. As the current study is developed within the context of the White Paper on Transport, the policies assumed, although with adjusted intensities to reflect the scenario- case characteristics, are placed within the spectrum analysed in the policy options[40] (in particular Policy Option 4) of the White Paper.

Fuel taxation in the CTS cases is in line with the initial proposal for the 2011 revision of the Energy Taxation Directive. Changes to minimum tax rates for transport reflect the switch from volume-based to energy content-based taxation and the inclusion of a CO2 tax component. Where Member States tax above the minimum level, the current rates are assumed to be kept unchanged. For motor fuels, the relationships between minimum rates are assumed to be mirrored at national level even if the existing rates are higher than the minimum rates. Tax rates are kept constant in real terms. Taxation on biofuels is also gradually introduced. Apart from the taxation of the CO_2 component of fuels no additional CO_2 tax was considered. Aviation is modelled to be part of the ETS from January 2012 as per Directive 2009/29/EC. For all other modes of transport only an overall carbon value is applied; biofuels are subject to the carbon value on a WTT basis penalising their carbon footprint during the production process and thus reflecting the Fuel Quality Directive. The ETS carbon price and the carbon value for the non-ETS sectors are assumed to be equal for all cases.

Table 13: Policies implemented in the transport sector, in the cases for the CTS study, additional to the Reference scenario policies

Extension of Regulation on CO_2 from cars 2009/443/EC	The regulation is expected to be prolonged until 2050, with an increase in intensity which is case dependent.
Vehicle energy efficiency standards	Alternatively to the CO_2 standards, energy efficiency standards are applied which apply on a Tank to Wheel basis and reflect the onboard efficiency of the vehicles.
CO_2 intensity of fuels - Fuel Quality Directive 2009/30/EC	Modelling parameters reflect the Directive, taking into account the lifecycle CO_2 emissions of the fuels.
Operational EURO Standards	Operational EURO Standards applying after 12th year of operation of vehicles from 2025 onwards.
Taxation	Excise taxes reflecting changes to minimum tax rates for transport, which account for the switch from volume-based to energy content-based taxation and the inclusion of a CO2 tax component.
Eco-driving	Improvement in overall driving efficiency resulting in lower energy consumption of vehicles
Infrastructure	Creation of infrastructure that allows more efficient mobility in the future

Measures related to the internalisation of external costs, internal market measures, other taxation measures (i.e. VAT on international passenger transport services; vehicle taxation; company car taxation) and measures related to transport planning are not included.

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[40] For a detailed list of policy options refer to the Impact Assessment of the White Paper on Transport.

In the CTS cases, the only policy to be adapted but within the range of values of the White Paper, are the CO_2 standards assumed. Within the scenarios also another policy regulation was introduced as alternative to the CO_2 standards: energy efficiency standards. The CO_2 standards were applied as is currently the case today on the tank-to-wheel, so the tailpipe emissions of the cars. The emissions were calculated, as is currently the case, based on the assumption that a vehicle will be fuelled with conventional fuels; no change is assumed throughout the scenarios. Energy efficiency standards were also applied on a “tank-to-wheel” basis therefore relate to the onboard efficiency of vehicles in combined cycle mode.

6 Overall trends in activity

All scenarios quantified project a growing transport activity, both for passengers and freight, in the future. The pace of activity growth is projected to be slower than past trends and to further slowdown in the long term. The projection exhibits decoupling of transportation activity growth from GDP growth, discontinuing past trends characterised by strong coupling of activity and GDP. The decoupling is mostly due to saturation factors and to productivity gains and is not uniform across the different transport modes. Aviation is a notable exception for which the projection displays high growth in the medium term with some slowdown only in the long term.

Additional policies and infrastructure investments could help further curbing growth of transport activity, as for example soft transport networks in urban areas and more intelligent logistics systems for freight. No explicit representation of such policies was included in the model-based projections. Change in transport activities is driven in the model by total cost of transportation, rather than restructuring measures.

Modal shifts are also driven by relative costs of transportation in this model-based study. The focus of the study was about comparing alternative fuel-technology combinations that would enable emission reduction, rather than on policies and measures that would induce strong modal shifts. The modal shifts obtained in the projections by scenario were due to changes in relative costs.

Table 14: Transportation Activity and GDP growth in the reference scenario and in the battery success scenario

	Average annual percentage change		
	1991-2010	2011-2030	2031-2050
GDP	1.69%	1.97%	1.48%
Passenger activity			
Reference scenario	1.45%	1.27%	0.60%
Battery success		1.16%	0.58%
Freight activity			
Reference scenario	1.84%	1.29%	0.58%
Battery success		1.19%	0.46%

Passenger activity levels rise in the Reference scenario by about 45.2% in 2050 compared to 2010 levels, whereas GDP grows by 98% during the same period. The activity levels as projected for the scenarios analysed varies between -1% and -5% compared to the Reference scenario in 2050. Also in freight transport the activity levels as projected for the scenarios do not diverge substantially from the Reference scenario levels; in the Reference scenario freight activity increases by 45.1% in 2050 compared to 2010 levels. In all scenario-cases modelled in this study the activity levels of freight transport decrease between -4% and -5% compared to the Reference scenario in 2050.

It is therefore clear that transport activity levels are strongly decoupled from GDP: although transport activity continues to rise throughout the time period, it does not rise at the same levels of the GDP increase (see Table 14). The GDP to activity elasticity is estimated to be around 0.6 in the time period from 2005 to 2050, in all scenario-cases modelled.

The high fuel prices in the dominant biomass scenario cases lead to higher average costs of transportation and therefore this scenario sees the lowest passenger activity. The electro-mobility cases see low average cost of transportation, relative to other scenarios, and therefore see the highest levels of activity, although there is a reduction compared to the Reference scenario. In all scenarios a large increase in the share of aviation compared to historic levels is projected following forecasts by Eurocontrol and IATA which expect such an increase. In relative terms the activity of public and road transport remain at the same shares, as not policies are assumed that promote public road transport.

Table 15: Passenger and freight transport activity and the shares of the different transport modes in the Reference scenario

		2005	Reference scenario	
			2030	2050
Passenger transport activity	**Gpkm**	**6240**	**8386**	**9453**
Private Road	% shares	75.1	71.6	69.4
Public Road		8.4	7.7	7.3
Rail		7.4	7.7	8.1
Aviation		8.4	12.6	14.7
Inland Navigation		0.6	0.6	0.5
Freight transport activity	**Gtkm**	**2495**	**3438**	**3863**
Road	% shares	72.2	73.2	73.5
Rail		16.6	16.8	16.9
Inland Navigation		11.2	10.0	9.6

The share of aviation increases throughout the scenarios up until 2050; due to the use of biokerosene in aviation, the emission reduction targets can be achieved although the share and use of aviation increases throughout the projection period. In freight transportation the share of road transportation is projected to decline, compared to historic levels to the benefit of rail which increases its share throughout the projection period. The share of inland navigation is projected to decrease slightly compared to historic levels and maintain its share.

7 Road transportation

This section focuses on the developments of road transportation within the scenario-cases modelled. For each storyline a general introduction is followed by the assumptions and the results for road transportation in the different scenario cases; results are differentiated between results for smaller road vehicles i.e. passenger cars and LDVs and larger road vehicles i.e. HDVs, buses and coaches[41].

7.1 “Dominant Electricity” context

The rationale of the “Dominant Electricity” context arises from the fact that electricity is an energy carrier that can be produced from many forms of primary energy providing a scope for diversification of primary energy sources. Under the conditions of a power generation sector which decarbonises over the time period considered, large scale electrification of transport leads to a reduction of the transport related CO_2 emissions and elimination of tailpipe emissions (TTW CO_2 emissions). The decarbonised electricity can either be used directly in battery-based cars or indirectly by producing decarbonised hydrogen for use in fuel cell cars.

In the context of the Dominant electricity case it is assumed that technologies related to electro-mobility (BEVs and FCEVs) will progress towards market maturity and will achieve cost and performance levels such that they become viable alternatives to current ICE technologies. This does not mean that vehicle purchasing cost will be as low as current ICE vehicles but that the technology progress and the effects of policy drivers, such as carbon pricing, taxation and the regulations, will be sufficient to incite consumers to opt for electro-mobile vehicles instead of ICEs.

It is assumed that conventional technologies also improve over time. The best available technology for ICE based vehicles for all road transport is assumed to improve in terms of efficiency between 0.8% and 1% per year in the time period from 2010 up to 2050. Compared to the Reference scenario improvements are assumed to be more pronounced in ICEs for heavy duty vehicles.

Regarding projection of battery and fuel cell costs to the future, the numerous studies published show various degrees of optimism and various magnitudes of learning-by-doing effects. Evidently there is high uncertainty about the future evolution of technology costs, which influences market prospects.

Anticipation about future market volumes and about the regulatory signals will certainly play a major role for achieving the learning-by-doing potential, as manufacturers incited by good anticipations increase R&D investment and configure mass production to deliver expected cost decreases.

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[41] In the model there is a differentiation between buses which are used exclusively in the urban environment and coaches which are used for inter-urban trips.

It is very difficult to resolve such uncertainties in an endogenous way. Instead the current study opted for quantifying alternative scenarios which assumed different degree of cost improvement for the key electro-mobility technologies.

Within a scenario context with electricity playing a dominant role in the road transport sector for driving decarbonisation towards 2050 it is worth to investigate about the future market shares of battery-based (grid charged) vehicles and of fuel cell vehicles. This exploration was based on scenarios involving different degrees of technology progress for the batteries and the fuel cells. This section focuses on providing a model-based comparison of the effects of battery versus fuel cell electric vehicles success in the transport sector. Under the assumptions of the Dominant Electricity scenario, two scenario-cases were developed assuming:

- Strong competitive advantage of vehicle technologies based on batteries (battery success) and alternatively
- Great improvement in costs and performance of fuel cell technology (fuel cell success).

The model projects to the future changes in the transport sector, regarding activity, energy consumption and vehicle stock, and the impacts on WTW and TTW CO_2 emissions, on final and primary energy demand.

In addition, the implications imposing CO_2 versus energy efficiency standards were analysed by quantifying two scenario-cases for each of the technology cases.

7.2 Battery success in the Dominant Electricity context

7.2.1 Technology assumptions

For the scenario-cases assuming success of battery-based vehicles, battery costs are assumed to significantly decrease from current levels, reaching a level of 141€/kWh in 2050 for the cheapest battery variety (see Figure 13). This achievement is in line with the R&D goals set in (USABC n.d.) and does not differ from anticipations by industry sources claiming that battery costs could fall to 163€/kWh already in 2020.[42]

In parallel the efficiency of battery electric cars is assumed to improve and reach levels by 2050 as low as between 0.1 and 0.15kWh/km depending on the car size and weight. The assumptions are in line with recent studies such as (Safarianova 2011) and (Offer, et al. 2011). Efficiencies for electric heavy duty vehicles and buses are assumed to improve at a slower pace, with average efficiencies projected to range in 2050 between 0.38kWh/km for small heavy duty vehicles and 1.27kWh/km for large heavy duty vehicles. Comparison of these assumptions with results found in the literature, as well as some sensitivity analysis, is provided in section 12.1.

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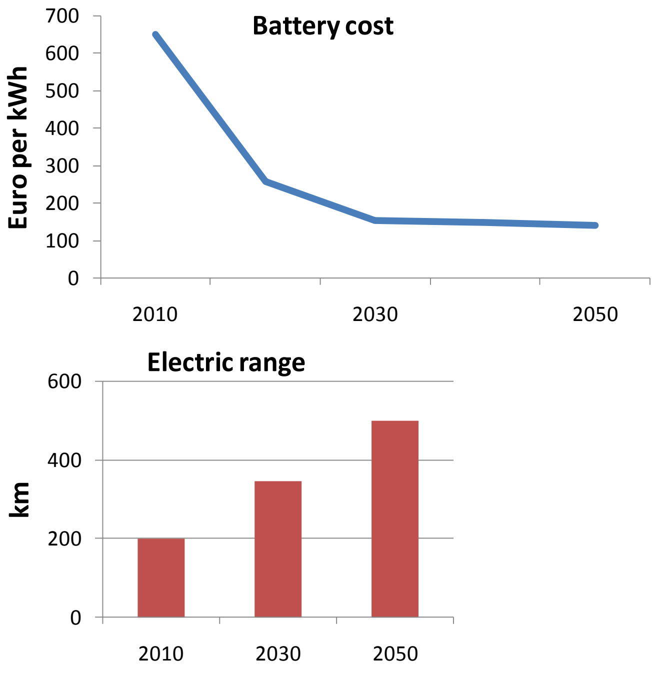
[42] Martin Eberhard, Co-founder of Tesla, since early 2009 electric vehicle engineering director at Volkswagen's Electronics Research Laboratory (ERL) in Palo Alto, California. http://electric-vehicles-cars-bikes.blogspot.com/2010/08/eberhard-500-mile-evs-by-2020.html (last viewed January 2011).

Thanks to these assumed improvements and also combined with assumptions regarding improvement in the density of batteries, the driving ranges of cars are projected to increase, reaching in the long term levels between 350 and 500 km depending on the car size (Figure 13). This allows using electric cars even for long trips, hence enabling better acceptance of electric vehicles by consumers. The choice of a car in the model depends on possibility of using the car in various trip cases which differ in trip distance; the increased range of electric cars renders their choice more economic according to the model formulations.[43] As explained in the section on the model description, each trip category is in the model further split in stylised trip lengths of different magnitudes corresponding to an assumed frequency distribution; when a vehicle technology is not able to cover the range for a specific trip length, the model assumes that the consumer faces additional costs which penalise the vehicle technology, making it uneconomic.

Battery electric technologies are assumed to improve for trucks but at a slower pace than for cars; the improvement turns out not being sufficient for making them competitive against ICE vehicles because of costs and range limitations, except for trucks used for special trip categories, as for example for delivering products in cities. Range limitation between 300 and 500km implies that the truck can be used only in medium length trips. Despite battery success assumed for this scenario-case, costs and range limitations remain substantial barriers to market penetration of electrified large heavy duty vehicles. Similar developments are projected for buses and coaches, with electricity penetration being economic only for trips in urban areas.

Figure 13 Assumptions on development of BEVs characteristics in the battery success case



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[43] See section 2 and appendix B for more information on the modelling techniques used for representing various trip distances through frequency diagrams

In addition to battery success, it is assumed that hydrogen fuel cell vehicles will substantially improve in costs and performance terms compared to current levels. Cost reductions are assumed to be approx. 5.8% per year on average between 2010 and 2050. The additional capital costs of fuel cell cars compared to conventional diesel vehicles are still between €9500 and €17000 in 2050 depending on the car size; the fuel cell stack and system costs are assumed to reach approx 190 €/kW by 2050. Despite this substantial improvement relative to current levels, the costs remain high not allowing fuel cells to be competitive in the market but only penetrate in niche market segments, mostly in trip segments for long distances.

7.2.2 Development of fuel distribution infrastructure

In the context of the battery success scenario, it is assumed that the entire recharging infrastructure needed for large-scale development of electric vehicles will be available by 2050 and almost entirely deployed already in 2030. According to the model-based findings, large-scale development of recharging infrastructure is essential for market acceptance of battery-based electro-mobility and its large scale diffusion.

It is assumed that the coverage will be such that for each battery electric vehicle there will be at least two slow charging points, one in the house or close to the house and one in the area nearby the working place; it is also assumed that a network of fast charging infrastructure will be available in public spaces. The infrastructure is assumed to be sufficient to service all operating electric vehicles.

Dedicated infrastructure is assumed also to develop for larger and heavier types of vehicles such as buses, trucks and coaches. Electricity demand by electric buses and small urban service electric trucks will be met by special urban points which may provide either battery swapping services or fast charging. In non-urban regions it is assumed that specific recharging points will be available for dedicated fleets of electric coaches and small electric trucks.

For hydrogen, the infrastructure is assumed to develop at a lesser extent as the low competitiveness of FCEVs drives anticipation of limited market penetration; this result was obtained after performing sensitivity analysis using the model.

Methane and LPG infrastructures are assumed to develop at a larger scale than in the Reference scenario to facilitate market penetration as the analysis has identified a positive contribution by these fuels in the medium-term in the context of the decarbonisation scenarios. Nevertheless, the density of refuelling stations is assumed to remain at a far lower level compared to the density of the recharging infrastructure. This complies with the view that methane and LPG fuels stay in niche markets under the assumptions of the dominant electrification scenario. Methane and LPG are projected to get some inroads into the heavy duty market segment where the penetration of electric vehicles is limited due to range and cost limitations.

7.2.3 CO_2 and energy efficiency standards

As for all scenario-cases the policies assumed are those found in Table 13. The CO_2 or energy efficiency standards assumed to be the main driver towards the uptake of electric vehicles are set for the dominant electricity scenario (battery success case) at the levels shown in Table 16. It is reminded that two alternative scenario-cases were quantified each implementing one of the two candidate regulations.

Table 16: CO_2 and energy efficiency standards in the battery success case

CO_2 standards (gCO_2/km)	2020	2030	2040	2050
Passenger cars	95	83	23	20
LDVs	135	110	62	55
2wheelers	70	50	18	8

Energy efficiency standards (Litres of gasoline equivalent per 100km)	2020	2030	2040	2050
Passenger cars	6	3.8	2.2	1.7
2wheelers	5	3.8	1.6	0.4
LDVs	8	5	2.6	1.45
HDVs	28	21	16	14.8
Buses	20	18	14	13

7.2.4 Main results: passenger cars and LDVs

Aside from the effects of the carbon values, that are rather small due to the limited effect of the carbon values on the overall cost of transportation for the levels considered in these scenarios, the main drivers for changes are the combination of the regulation, either CO_2 or energy efficiency standards and the substantial improvement in the cost-technology performance characteristics of battery based vehicles, both pure battery electric vehicles and plug-in hybrids.

The regulation has a supply side effect obliging manufacturers to offer vehicle models that emit limited amounts of CO_2 emissions or are highly efficient depending on the regulation imposed; due to the regulation becoming stricter over time the type of vehicles offered throughout the projection period becomes continuously more efficient and/or less emitting.

The assumed dynamic progress of batteries in terms of cost reductions and in terms of performance, such as longer ranges and longer battery life times, induces better acceptance by consumers who gradually choose battery based cars increasingly.

The dynamic improvement of batteries over time drives a vehicle stock structure which evolves over time (see Table 17); first conventional hybrids and at a far lesser extent LPG and methane fuelled cars enter the market, and towards the end of the time period pure BEVs gain considerable shares of the stock.

As it is assumed that FCEVs do not exhibit a sufficient cost reduction trend, they are not competitive except for specific trip lengths and only in the long term when the cost reduction allows them to get a small market share, in specific market segments involving long distance trips.

Methane and LPG cars get a small but noticeable market share in the scenario-case with CO_2 standards regulation, as they are energy carriers with low carbon intensity than gasoline or diesel; nonetheless because of lower density of infrastructure and the substantial cost reduction in the long-term of battery based vehicles, methane and LPG cars are gradually pushed out of the market.

Table 17: Stock of passenger cars and LDVs in the battery success case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	87.6	86.0	44.8	5.7	-42.8	-81.8
Gasoline Conventional	150.4	128.5	71.8	6.4	-78.7	-144.0
Hybrid	0.0	28.3	66.6	22.4	66.6	22.4
LPG and CNG	5.6	22.0	32.1	11.8	26.5	6.2
Ethanol car	0.0	0.1	0.7	0.7	0.7	0.7
Plug-in Hybrid	0.0	19.4	52.3	84.9	52.3	84.9
BEVs	0.0	0.2	25.4	156.9	25.4	156.9
FCEVs	0.0	0.0	2.5	37.3	2.5	37.3
Total	**243.6**	**284.5**	**296.1**	**326.2**	**52.5**	**82.6**

Table 18: Stock of passenger cars and LDVs of age less than 4 years, in the battery success case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	48.5	25.8	16.7	2.4	-31.9	-46.1
Gasoline Conventional	67.0	41.4	26.5	2.6	-40.5	-64.4
Hybrid	0.0	24.6	29.6	9.8	29.6	9.8
LPG and CNG	2.9	10.7	15.7	5.1	12.8	2.2
ethanol car	0.0	0.1	0.4	0.3	0.4	0.3
Plug-in Hybrid	0.0	18.2	24.9	35.3	24.9	35.3
BEVs	0.0	0.2	19.8	65.3	19.8	65.3
FCEVs	0.0	0.0	1.9	17.5	1.9	17.5
Total	**118.4**	**121.0**	**135.5**	**138.3**	**17.1**	**19.9**

As can be seen in Table 18 the new vehicle sales follow a pattern in line with the development of the technology progress; in 2020 conventional hybrid cars gain large market shares, as do LPG and methane vehicles and plug-in hybrids at a lesser extent; by 2030 pure electric vehicles start penetrating the market obtaining a share of 14.6% in new car sales. This early stage penetration of pure electric vehicles is consistent with the prospect of domination (47.2% of new market share in 2050) of the market for new registrations by 2050 allowing full exploitation of learning-by-doing possibilities. Together with plug-in hybrids their share increases to 72.7% by 2050. Methane and LPG vehicles achieve their maximum penetration of 11.6% of new vehicle sales in 2030. Beyond 2030 the very high progress of grid connected vehicles (BEVs and PHEVs) has a detrimental effect on all other kinds of vehicles.

7.2.5 Final energy demand

Final energy demand for passenger cars and LDVs decreases by 67% compared to 2005. This enormous decrease in final energy demand is driven by the penetration of grid connected vehicles which are very efficient in final energy demand terms.

Although liquid fuels continue to be the dominant delivered fuel form for final energy demand in private passenger road transport, its share is greatly reduced from over 97% to under 50% in 2050. Demand for electricity starts increasing substantially beyond 2030 when PHEVs and BEVs start penetrating the market at a large scale; by 2050 electricity represents 30% of the delivered fuel.

Gaseous fuels that only made up 2.7% of the total energy demand in 2005 see their share rising up to 15.3% in 2030 and decreases back to 9.5% in 2050. Beyond 2030 the consumption of gaseous fuels declines as these kind of vehicles are pushed out of the market due to the improvements in battery based vehicles.

Table 19: Final energy demand of passenger cars and LDVs by delivered form in the battery success case with CO_2 standards

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Liquid Fuels	183.4	155.6	108.5	29.5	-74.9	-153.9
Gaseous Fuels	5.0	15.3	21.1	6.4	16.1	1.4
Liquefied hydrogen	0.0	0.0	0.6	7.6	0.6	7.6
Electricity	0.0	1.5	5.9	18.6	5.9	18.6
Total	**188.4**	**172.4**	**136.1**	**62.1**	**-52.3**	**-126.3**

Liquid fuels include both oil products and biofuels. Whereas the demand for oil decreases by 87% from 2005 levels, amounting to only 24Mtoe by 2050; oil demand represents 38.7% of total final energy demand in 2050. Despite the high share, which is due to the very high efficiency of grid connected vehicles compared to ICES, the dependence of private road transportation on oil is drastically reduced. Biofuels consumption on the contrary increases throughout the projection period and already increases 7 fold from 2005 to 2020; the main biofuel used is biodiesel used in blending with diesel oil. By 2030 biofuel consumption increases to 17Mtoe and reaches 10Mtoe by 2050, a reduction due to the total reduction of liquids.

Table 20: Final energy demand of passenger cars and LDVs by fuel type in the battery success case with CO_2 standards

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Oil products	186.2	151.3	104.8	24.4	-81.4	-161.8
Natural Gas	0.5	3.8	7.8	1.3	7.3	0.8
Biomass	1.7	15.8	17.0	9.7	15.3	8.0
Hydrogen	0.0	0.0	0.6	8.2	0.6	8.2
Electricity	0.0	1.5	5.9	18.6	5.9	18.6
Total	**188.4**	**172.4**	**136.1**	**62.1**	**-52.3**	**-126.3**

The share of natural gas, included in gaseous fuels, increases substantially in the medium term; from very low market shares in 2005 the share increases to approx. 8Mtoe by 2030 where its consumption peaks. In 2050 its share in final energy demand reduces to below 1Mtoe.

7.2.6 What if energy efficiency standards were applied instead of CO_2 standards?

When energy efficiency standards are applied instead of CO_2 standards the share of FCEVs in passenger cars and LDVs reduces drastically, as can be seen in Table 21, because although FCEVs have no tailpipe emissions, they do not comply with extremely strict energy efficiency standards. The absence of FCEVs does not have a detrimental effect on emissions, as they are replaced by grid connected vehicles.

By 2050, with energy efficiency standards, the share of battery electric cars and LDVs reaches approx. 50% of the total stock, with plug-in hybrids representing 38% and conventional[44] vehicles 12.4%; battery based vehicles therefore represent 88% of total stock. This contrasts results for the CO_2 standards where BEVs represent 48% of share, plug-in hybrids 26% and conventional vehicles 14.4%; the share of battery based vehicles is therefore lower at 74% in the carbon regulation case. With CO_2 standards grid connected vehicles do not reach the same share due to the competition of other zero tailpipe emission vehicles such as FCEVs that reach a share of 11.4% in 2050; by comparison FCEV in the energy efficiency standards case have a share of 2% in the same year. In the midterm the change from CO_2 standards to energy efficiency standards also affects the share of LPG and methane powered vehicles; these achieve a higher share under CO_2 standards because they use energy forms with a rather low carbon content. These vehicles are penalised under energy efficiency standards because their efficiency is lower than that of conventional gasoline or diesel cars.

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[44] Conventional vehicles include the current ICE technology and the hybrid ICE technology; plug-in hybrid vehicles are reported separately

Table 21: Stock of private cars and LDVs in the battery success case with CO_2 and energy efficiency standards

	2030		2050	
(million vehicles)	CO2 standards	Efficiency standards	CO2 standards	Efficiency standards
BEVs	25	26	157	163
Plug-in Hybrids	52	53	85	124
FCEVs	2	3	37	6
LPG and CNG	32	31	12	1
Conventional and Hybrids	184	183	35	39
Total	**296**	**295**	**326**	**333**

The results therefore show that under the same techno-economic and infrastructure development assumptions the penetration of battery based vehicles and FCEVs changes significantly depends on the regulatory option chosen.

With the implementation of energy efficiency standards battery based vehicles, BEVs and PHEVs, are by far the dominant technology virtually eliminating all other technologies outside of specific niche uses. The CO_2 standards in this context allow for a more diversified use of technologies.

7.2.7 Main results: freight and public transport

Despite the positive development in techno-economic performance of batteries, the progress is not sufficient to electrify road freight transport on a large scale because of technical limitations relating to the weight and volume of battery packs as well as costs; also the development of fuel cell technology is not sufficient for this technology to penetrate this transport mode.

Table 22: Stock of HDVs, buses and coaches in the battery success case with CO_2 standards

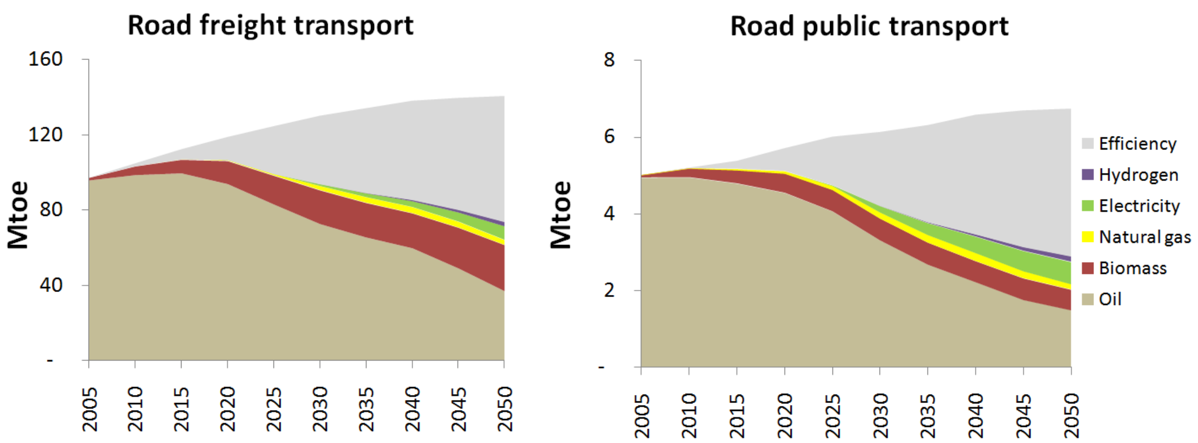
(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	8.6	10.1	7.0	4.0	-1.6	-4.6
Hybrid	0.0	0.4	3.9	5.0	3.9	5.0
LPG and CNG	0.0	0.1	0.4	1.0	0.4	1.0
Electric	0.0	0.0	0.3	2.4	0.3	2.4
Fuel Cell	0.0	0.0	0.0	0.4	0.0	0.4
Total	**8.6**	**10.6**	**11.6**	**12.7**	**3.1**	**4.1**

The main drivers for the progressive reduction in energy consumption in freight and public transport are the carbon value and the improvements in efficiency for conventional and hybrid ICE technology. As can be seen in Table 22, the main technologies that penetrate the market are therefore efficient ICEs and hybrid vehicles. The penetration of electric based vehicles in

2030 is almost inexistent but due to the high progress in techno-economic performance of batteries assumed, electric vehicles reach a 20% share by 2050; this share corresponds to buses and freight transport mainly in urban areas where electric vehicles can economically operate despite range limitations.

As can be seen in Figure 14, the efficiency gains[45] for road freight transport obtained through the improvement of ICEs and the market penetration of hybrid vehicles allows for efficiency gains of just above 50% compared to a frozen technology case at 2005 levels. For buses and coaches the efficiency gains compared to 2005 are 57%.

Figure 14: Energy consumption incl. Efficiency gains compared to 2005 levels in the battery success case



Final energy demand for freight and public road transport decreases by 25.1% between 2005 and 2050 in this scenario-case; although oil products continue to represent 50% of final energy demand, they decrease by 61.7% compared to 2005 levels. The share of biofuels increases from below 2% in 2005 to almost 33% in 2050.

Table 23: Final energy demand of HDVs, buses and coaches by fuel in the battery success case with CO_2 standards

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Oil products	101	99	76	39	-25	-62
Natural Gas	0	0	2	3	2	3
Biomass	1	13	18	25	17	24
Hydrogen	0	0	0	3	0	3
Electricity	0	0	1	8	1	8
Total	**102.4**	**111.7**	**98.1**	**76.7**	**-4**	**-26**

Biomass is for road freight and public road transportation together with energy efficiency the only option to obtain significant reductions in emissions. The other options limited to specific

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[45] Efficiency gains are defined as the additional energy needed in order to fulfil the activity by assuming that energy per activity unit remained constant at the levels of 2005

uses are electricity and natural gas; the share of electricity rises to 10.2% and the share of natural gas increases to 3.4%.

7.3 Fuel cell success in the Dominant Electricity context

The fuel cell success case presented below adds to the strong progress in the techno-economic performance of battery based vehicles also a strong improvement in the techno-economic performance of fuel cell based vehicles.

7.3.1 Technology assumptions

In the fuel cell success case a breakthrough in the development of the fuel cell technology is assumed, leading to high reduction in costs. The assumptions taken for this case are based on (McKinsey 2010) which claims that fuel cell stack costs could drop to 43€/kW by 2020 from approx. 500€/kW today. According to (McKinsey 2010) the improvements will be driven by engineering developments, use of different materials and limited use of scarce ones like platinum, as well as improvements in production technology. Further development, beyond 2020, is assumed to be moderate; costs are assumed to reduce on average at a 6% annually in the period 2011-2050 (but a reduction of 21% per year is achieved until 2020), as can be seen in Table 24. Other literature sources also claim that fuel cell stack costs could decrease substantially in the short to midterm: (Offer, et al. 2011) claims that costs could decrease to 35$/kW by 2030 while (Safarianova 2011) states that fuel cell stack cost could decrease to 60 €/kW already by 2015.

Specific energy consumption of fuel cell electric cars is assumed to reach a range between 0.7 and 0.9 kg H_2/100km by 2050 depending on car size (less than 3 gasoline equivalent litres per 100 km). Several studies, including (Safarianova 2011), (Offer, et al. 2011) and (Sekanina 2006), confirm similar values to the above.

Table 24: Assumptions on the development of fuel cell stack and system costs in the fuel cell success scenario

(Euro/kW)	2010	2020	2030	2040	2050
Fuel cell stack and system costs	800	88	73	60	50

The additional cost of a medium sized fuel cell car compared to a conventional diesel car is assumed therefore to drop from roughly 60000€ today to approx. 7000€[46] in 2020 making them more competitive with conventional technologies; by 2050 the additional cost declines to 4500€. In the fuel cell success scenario it is assumed that fuel cells will also be adapted to LDVs and light HDVs.

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[46] Assuming that the fuel cell provides 75 kW power output and that the fuel cell stack and system (periphery) costs are 800 €/kW in 2010 and 90 €/kW in 2020 (43 €/kW the fuel cell stack cost and 45 €/kW the system cost).

Efficiency of HDVs powered by ICEs is assumed to improve beyond reference scenario levels and it is assumed that no other technology will develop so as to be fully competitive with ICEs for this transport mode.

The comparison of the assumed values regarding fuel cell stack costs with values from other literature sources together with a brief sensitivity of the results can be found in section 12.2.

The battery development assumed for this scenario is the same as the one described in the previous scenario-case “battery success”. In other words, this scenario case assumes full technology success for both the batteries and the fuel cells.

7.3.2 Development of fuel distribution infrastructure

In the context of the fuel cell success case scenario, it is assumed that the necessary refuelling and distribution infrastructure for hydrogen is widely available by 2050 and almost entirely deployed already in 2030. The model simulates that the large-scale development of refuelling infrastructure is essential for market acceptance of hydrogen based electro-mobility and its large scale diffusion.

The hydrogen refuelling and distribution infrastructure will be additional to the recharging infrastructure that will develop along the same lines as in the battery success case. Also the infrastructure for other road transport fuels develops in the same way as in the battery success case.

Hydrogen production is assumed to develop based on electrolysis using the power generation mix of the decarbonisation scenario in which carbon emissions per unit of electricity delivered are assumed to decrease substantially over time and become close to zero already by 2040.

The simulations of hydrogen supply, hydrogen prices and energy system implications are performed using the core PRIMES model.

Hydrogen prices are estimated to be significantly higher than electricity prices (per unit of energy delivered to final consumers), throughout the projection period, because of losses in electrolysis, the cost of electrolysis and the cost of hydrogen transportation through a network of high pressure and medium pressure dedicated pipelines.

The relatively high hydrogen prices (estimated between 140 and 170 EUR'08/MWh hydrogen in wholesale markets with additional costs for transportation and distribution) constitute a major drawback for market penetration of hydrogen in the transport sector.

7.3.3 CO_2 and energy efficiency standards

The CO_2 or energy efficiency standards assumed to be the main driver towards the uptake of electro-mobility are at the levels shown in Table 25 which are roughly unchanged from the battery success case. It is reminded that two alternative scenario-cases were quantified each implementing one of the two candidate regulations.

Table 25: CO_2 and energy efficiency standards in the fuel cell success case

CO2 standards (gCO2/km)	**2020**	**2030**	**2040**	**2050**
Passenger cars	95	78	23	20
LDVs	135	110	62	55
2wheelers	70	50	18	8

Energy efficiency standards (Litres of gasoline equivalent per 100km)	**2020**	**2030**	**2040**	**2050**
Passenger cars	6	4	2.2	1.8
2wheelers	5	3.8	1.6	0.4
LDVs	8	5	3	1.5
HDVs	28	21	16	14.8
Buses	20	18	14	13

7.3.4 Main results: passenger cars and LDVs

As was the case in the battery success scenario the main drivers for changes are the combination of regulation and the substantial improvement in cost-technology performance of vehicles; whereas in the battery success case only battery technology vehicles reduced their costs and improved their performance in the fuel cell case also the fuel cell vehicles are assumed to improve drastically.

Although the large drop in costs for fuel cells takes place at an early stage, significant market penetration of fuel cell vehicles as projected by the model takes place from 2030 onwards, when the cost reduction is sufficient to accelerate market penetration and the hydrogen infrastructure is widely available.

Table 26: Stock of passenger cars and LDVs in the fuel cell success case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	87.6	85.9	40.3	7.3	-47.2	-80.3
Gasoline Conventional	150.4	128.3	62.9	8.7	-87.6	-141.7
Hybrid	0.0	28.0	58.0	24.8	57.9	24.8
LPG and CNG	5.6	21.9	29.1	14.3	23.5	8.7
Ethanol car	0.0	0.1	0.6	0.8	0.6	0.8
Plug-in Hybrid	0.0	19.1	45.6	58.3	45.6	58.3
BEVs	0.0	0.2	21.4	92.1	21.4	92.1
FCEVs	0.0	0.9	38.4	127.9	38.4	127.9
Total	**243.6**	**284.4**	**296.3**	**334.3**	**52.7**	**90.7**

In this scenario where we see strong improvement in the techno-economic performance of both battery and fuel cell vehicles the new registrations of FCEVs reach 54 million in 2050 up from 17.7 million in the battery success case, whereas grid connected vehicles (BEVs and PHEVs) reach approx. 64million vehicles, down from 101 million in the battery success scenario. In 2030 the share of FCEVs in the new stock of vehicles was already projected to be 16.8% and is thus consistent with the prospect of higher market shares in 2050 which allow to take advantage of learning by doing possibilities. BEVs and PHEVs together have a share of 17.6% in 2030.

Table 27: Stock of passenger cars and LDVs of age less than 4 years, in the fuel cell success case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	48.5	25.8	14.3	3.1	-34.2	-45.4
Gasoline Conventional	67.0	41.2	22.2	3.5	-44.8	-63.4
Hybrid	0.0	24.2	24.9	10.9	24.9	10.8
LPG and CNG	2.9	10.7	13.7	6.2	10.8	3.3
ethanol car	0.0	0.1	0.3	0.4	0.3	0.4
Plug-in Hybrid	0.0	17.9	20.8	24.4	20.8	24.4
BEVs	0.0	0.2	16.7	39.3	16.7	39.3
FCEVs	0.0	0.9	22.8	53.7	22.8	53.7
Total	**118.4**	**121.0**	**135.8**	**141.5**	**17.4**	**23.1**

Despite the impressive developments in cost reduction of fuel cell vehicles, the additional fuel costs of hydrogen compared to electricity make the BEVs an overall cheaper option. FCEVs are by definition less efficient than electric vehicles, although they are much more efficient than ICEs, due to the onboard fuel cell transforming the hydrogen into electricity to power the electric motor. Further the costs of hydrogen as a fuel are by definition higher than electricity as in these scenarios it is assumed that hydrogen is produced through electricity via electrolysis. For hydrogen to reach the refuelling stations there are therefore more conversions leading to transformation losses and higher costs. Hydrogen through electrolysis is assumed to be the most efficient way to obtain decarbonised hydrogen, as it is assumed in the context of these scenarios that the power generation sector will be almost fully decarbonised by 2050. Hydrogen production via electrolysis has also the advantage of optimising the use of intermittent renewables.

Due to the existence of two technologies, FCEVs and BEVs, which comply with the strict CO_2 regulations the range limitation of BEVs plays a higher role in the decision making. Whereas in the battery success case the uptake of hydrogen vehicles was limited to long ranges where BEVs cannot compete, due to the cost reduction of FCEVs these take up a share of long and medium range trips.

Methane and LPG vehicles follow a similar development to the battery success case; the amount of vehicles increases in the midterm and then declines towards to the end of the projection period due to the competition of the more efficient and less emitting battery based and fuel cell based vehicles and due to the strict regulation.

7.3.5 Final energy demand

Final energy demand, for private transportation, declines by 62% between 2005 and 2050 reaching 71Mtoe in 2050. This very large reduction in final energy demand is driven by the penetration of both fuel cell vehicles, with significant lower energy consumption than ICEs, and highly efficient grid-connected vehicles.

Table 28: Final energy demand of passenger cars and LDVs by delivered form in the fuel cell success case with CO_2 standards

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Liquid Fuels	183.4	155.1	95.3	28.3	-88.1	-155.1
Gaseous Fuels	5.0	15.2	19.0	8.0	14.0	3.0
Liquefied hydrogen	0.0	0.2	8.6	23.8	8.6	23.8
Electricity	0.0	1.4	5.0	11.3	5.0	11.3
Total	**188.4**	**172.1**	**128.0**	**71.3**	**-60.4**	**-117.1**

Whereas in the battery success scenario oil based products (and the fuels delivered in liquid form) maintained the highest share, in the fuel success case scenario hydrogen and oil products have the same share in final energy demand by 2050. Oil products represent only 24Mtoe by 2050, which means as in the battery success case that the dependence on oil products in private transportation is radically reduced. The share of oil and hydrogen in final energy demand is 34%. Electricity demand represents 16% of final energy demand in 2050 although the share of BEVs and PHEVs in total share of private vehicles is higher than the share of FCEVs due to the higher efficiency of the BEVs.

Table 29: Final energy demand of passenger cars and LDVs by fuel type in the fuel cell success case with CO_2 standards

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Oil products	186.2	150.4	92.3	24.5	-93.8	-161.7
Natural Gas	0.5	3.7	7.0	1.7	6.5	1.2
Biomass	1.7	16.3	15.0	9.3	13.3	7.6
Hydrogen	0.0	0.2	8.6	24.5	8.6	24.5
Electricity	0.0	1.4	5.0	11.3	5.0	11.3
Total	**188.4**	**172.1**	**128.0**	**71.3**	**-60.4**	**-117.1**

The share of natural gas increases in the medium term and reduces again in the long term as was the case in the battery success case. Natural gas final energy demand achieves approx. 7Mtoe in 2030 and decreases back to almost 2Mtoes in 2050.

7.3.6 What if energy efficiency standards were applied instead of CO_2 standards?

As was the case in the battery success scenario if energy efficiency standards are introduced instead of CO_2 standards the share of FCEVs goes back considerably; this is still the case in this scenario although there is a much stronger improvement in the techno-economic performance of FCEVs.

Up to 2030 the implications of the two different kinds of regulation can be mainly observed in the development of methane and LPG vehicles which is lower in the case of energy efficiency standards than the CO_2 standards, due to the lower efficiency of these vehicle types.

Table 30: Stock of private cars and LDVs in the fuel cell success case with CO_2 and energy efficiency standards

	2030		2050	
(million vehicles)	CO2 standards	Efficiency standards	CO2 standards	Efficiency standards
BEVs	21	22	92	150
Plug-in Hybrids	46	45	58	109
FCEVs	38	38	128	42
LPG and CNG	29	29	14	1
Conventional and Hybrids	162	163	42	33
Total	**296**	**296**	**334**	**335**

In 2050 when the standards become very stringent to push towards a strong reduction in emissions, the difference between the two standards becomes even more visible than in the battery success scenario. In the CO_2 standard case, of which the results were presented above, FCEVs gain a considerable share of new registrations by 2050; in contrast in the energy efficiency standard scenario the share of FCEVs reduces to levels below the battery success case with CO_2 standards where the cost reductions of FCEVs were not as strong. The share of FCEVs declines from approx. 38% in 2050 under the CO_2 standards to 12.5% in 2050 under the energy efficiency standards; the share of PHEVs and BEVs rises to 77.3% in 2050 under the energy efficiency from 46% under CO_2 standards in 2050.

The strong energy efficiency standards implemented to obtain the strong reduction in emissions has a crowding out effect, allowing only the very efficiency BEVs and PHEVs to develop.

7.3.7 Main results: freight and public transport

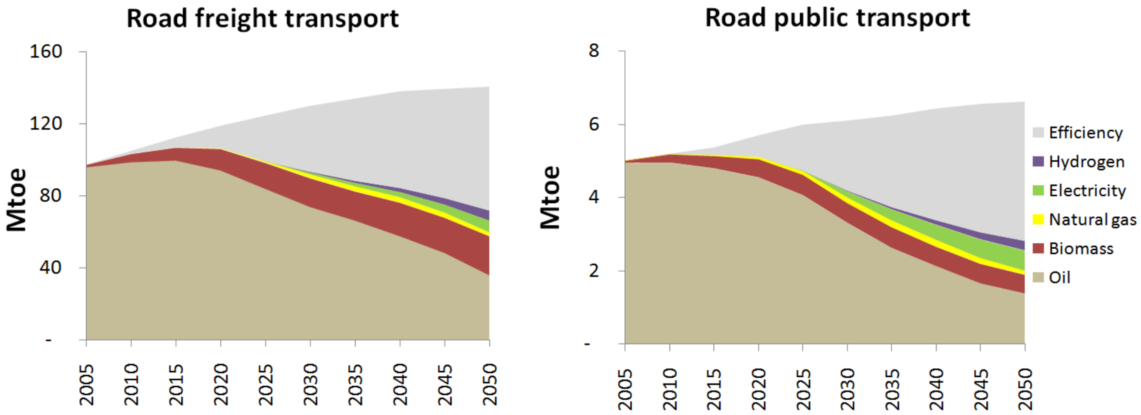
Despite the strong developments in fuel cells and battery based vehicles these technologies are assumed not to develop sufficiently from a technical perspective to be an option to ICEs for large scale heavy duty vehicles, in particular for long distance trips.

Table 31: Stock of HDVs, buses and coaches in the fuel cell success case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	8.6	10.1	7.0	3.7	-1.6	-4.8
Hybrid	0.0	0.4	3.9	4.7	3.9	4.7
LPG and CNG	0.0	0.1	0.4	0.9	0.4	0.9
Electric	0.0	0.0	0.3	2.2	0.3	2.2
Fuel Cell	0.0	0.0	0.1	1.2	0.1	1.2
Total	**8.6**	**10.6**	**11.6**	**12.7**	**3.0**	**4.1**

As is clearly visible from the stock composition the core of freight and public transport remains based on efficient ICEs and hybrids, as was the case in the battery success case. It is also visible that the amount of vehicles which become electric vehicles in the battery success case remain roughly unchanged; therefore the urban areas touched by these vehicles remains electric based. A small emergence of FCEVs can be observed in 2050 with penetration mainly in the small to middle classes of heavy duty vehicles, as the cost-performance characteristics of FCEVs are not competitive with conventional ICEs and hybrids for larger vehicles. The FCEVs therefore take a market share which cannot be taken up by electric vehicles due to range limitations.

Figure 15: Energy consumption incl. Efficiency gains compared to 2005 levels in the fuel cell success case



The heavy duty-long distance categories are therefore untouched by FCEVs or electric vehicles. As was the case in the battery success scenario these categories continue to rely on efficient ICEs and hybrids. Efficiency gains compared to 2005 are 49% for road freight transport and 58% for public transport; the efficiency gains are higher than in the battery success case due to the penetration of FCEVs which are more efficient than ICEs and hybrids.

Final energy demand for freight and public road transport decreases by approx. 27% between 2005 and 2050 in this scenario case; although oil products still represent approx. 50% of final energy demand, their amount decreases by 63% compared to 2005 levels; biomass reaches a share of 30%. The demand for both oil and biomass decreases slightly due to the penetration of FCEVs in transport segments normally covered by these fuels.

Table 32: Final energy demand of HDVs, buses and coaches by fuel type in the fuel cell success case with CO_2 standards

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Oil products	101	99	77	37	-24	-64
Natural Gas	0	0	2	2	2	2
Biomass	1	12	17	22	15	21
Hydrogen	0	0	0	6	0	6
Electricity	0	0	1	7	1	7
Total	**102.4**	**111.7**	**97.6**	**74.7**	**-5**	**-28**

7.4 “Dominant Biomass” context

The biomass context analyses the case in which the developments of battery based vehicles and fuel cell based vehicles is not as impressive and optimistic as assumed in the dominant electricity cases; it is assumed that the failure of these technologies to improve their techno-economic performance is known sufficiently in advance to steer the R&D system in order to allow for stronger improvements of ICEs, incl. hybrids, to develop the technologies towards production of competitive and sustainable second generation biofuels on a very large scale and to put in place agricultural policies for production of the necessary feedstock for biofuels.

The policies influencing this evolution are not assumed to change in this scenario, only the CO_2 and energy efficiency standards, as in all scenarios, are adapted to facilitate the penetration of the remaining options; the techno-economic performances of technologies are changed. As the battery based and fuel cell based technologies are not available at the same degree, the system needs to rely on the remaining options: (1) highly efficient ICEs, incl. hybrids, (2) biofuels and (3) the complementary use of methane. Through the increased use of these options it is assumed that stronger economies of scale will develop allowing for further improvements and cost reductions in these options compared to the dominant electricity context.

7.4.1 Technology assumptions

As the transport system needs to change towards emission reduction, the market prospects drive higher improvements in energy efficiency for ICEs and hybrids than in the dominant electricity scenarios. Combined with higher availability of less costly biofuels, the transport system can deliver equal emission reductions as in the dominant electricity context.

Compression and spark ignition engine technologies are assumed to undergo extensive improvement regarding their fuel consumption and the related CO_2 emissions. The improvements are assumed to relate to a combination of engine and non-engine improvements, for ICEs and advanced hybrid vehicles. Engine improvements include engine downsizing and turbo-charging, while non-engine improvements include advanced aerodynamic designs and lighter materials.

The best available technology for ICE cars is expected to improve at an average rate of 1.3% per year between 2010 and 2050, with big cars improving at faster rates than small cars. At the end of the time period the best available technology for medium sized gasoline cars will have a nominal consumption of 4.1l/100km while a hybrid car of the same size 2.9l/100km. Heavy duty vehicles improve on average at a rate approx. 1.4% per year; the nominal consumption of the heavy duty vehicles decreases by over 40% compared to 2005.

Furthermore it is assumed that the costs of vehicle adaptations required to burn pure or high percentage blends biofuels will decrease and also that cars will be able to run on different blends or pure biofuels without the need of substantial modifications.

Along with vehicle progress, large improvements are expected in the technologies producing biofuels. The scenario assumes that large scale R&D effort combined with effectively supported industrial (e.g. biorefineries) and agricultural developments will deliver the following improvements, which have been simulated using the PRIMES Biomass model[47]:

- ***Reduce the cost of production of second generation biofuels***. Currently both ethanol from ligno-cellulose and BTL diesel cost more than 0.7 euro/litre (wholesale) at existing demonstration plants. It is assumed that larger scale demonstration will result in the medium-term to costs of around 0.4 euro/ litre for ethanol from ligno-cellulose and to around 0.5 euro/ litre for BTL. Such costs would make second generation biofuels able to compete successfully against their fossil equivalents as projected in the reference case. Such developments will mean that any financial support measures required to stimulate early penetration of second generation biofuels can be phased out beginning in the 2020's.
- ***Develop a stable minimal supply of biomass***, able to fulfil the needs of the biofuel production facilities at all times
- ***Development of 2nd generation production plants*** in the context of bio-refineries that are able to optimally use the biomass and produce a variety of biofuel outputs.
- ***Develop low quality BTL fuels*** to compete with relatively cheap heavy fuel oil that is currently used in large ship diesel engines.

Techno-economic performance of battery based vehicles is assumed to improve at a slower pace compared to the dominant electricity context. By 2050 the lowest battery costs are assumed to stand at 250€/kWh; such values are broadly consistent with projections by (IEA 2009). Ranges of electric cars reach between 250 and 350km, instead of values up to 500km as in the dominant electricity scenarios and their efficiency improves at 0.6% per year on average between 2010 and 2050.

Also for other road transport technologies higher battery costs and lower ranges than the dominant electricity scenarios are assumed, with ranges not rising above 340km for small heavy duty vehicles or above 290km for large trucks. Electric vehicles see a definite

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[47] Using this model, the study has determined the upper bounds of biofuel use over time and the prices of biofuel commodities.

improvement compared to the Reference scenario, but their progress is more limited compared to the dominant electricity scenarios.

Hydrogen vehicles are not expected to improve in an optimistic way as the fuel cell stack cost is assumed not to decrease below 150 €/kW by 2050.

7.4.2 Development of fuel distribution infrastructure

For new technologies and fuels to benefit from consumer acceptance and therefore obtain large scale diffusion the fuel distribution infrastructure needs to develop.

To allow for the large scale diffusion of liquid biofuels additional outlets need to be available at filling stations; these additions will require only the addition of a tank and an outlet for refuelling and is assumed to have relatively low costs, compared to the costs of e.g. constructing new fuelling stations. For this scenario it is assumed that biofuel distribution infrastructure develops widely, allowing the consumer the choice between different blends and pure biofuels. The choice of the consumer will depend on the availability and cost of the fuel.

Methane and LPG infrastructure in the dominant biomass scenarios is assumed to develop at a larger scale than in the Reference scenario and the dominant electricity scenarios. LPG and methane have a lower carbon content than gasoline or diesel, and vehicle technologies are commercially mature today.

Recharging infrastructure is assumed to develop at a rather limited extent in the medium term as the progress in batteries does not justify large scale development of the infrastructure; nevertheless recharging infrastructure is projected to develop fully in the long term. For hydrogen refuelling infrastructure a limited amount of stations is foreseen, with higher density in urban areas compared to inter-urban areas.

7.4.3 CO_2 and energy efficiency standards

As for all scenario-cases the policies assumed are those found in Table 13. The CO_2 or energy efficiency standards assumed are adjusted to higher (less strict) levels than those of the dominant electricity scenarios to facilitate the penetration of the remaining available technological options and fuels, as it is assumed that both battery and fuel cell based vehicles do not progress to the extent of the dominant electricity scenarios. The level of the regulation can be seen in Table 33. It is reminded that two alternative scenario-cases were quantified each implementing one of the two candidate regulations.

Table 33: CO_2 and energy efficiency standards in the dominant biomass case

CO2 standards (gCO2/km)	**2020**	**2030**	**2040**	**2050**
Passenger cars	95	90	58	42
LDVs	135	130	100	75
2wheelers	70	65	55	40

Energy efficiency standards (Litres of gasoline equivalent per 100km)	**2020**	**2030**	**2040**	**2050**
Passenger cars	6	4	3.1	2.5
2wheelers	5	4	3	2.35
LDVs	8	6	4.5	3.4
HDVs	28	26	21	18
Buses	20	19	17	15

7.4.4 Main results: passenger cars and LDVs

This scenario projects to the future a significantly different structure of the stock of vehicles, compared to the dominant electricity scenarios due to the limited development of battery and fuel cell based vehicles.

In 2030 the stock remains dominated by conventional ICEs and hybrids; these are complemented by plug-in hybrids as well as by methane and LPG vehicles. The penetration of BEVs and FCEVs is marginal.

By 2050 the stock changes with plug-in hybrids taking a significant market share. The total amount of plug-in hybrids by 2050 is higher in the dominant biomass context than in the dominant electricity context. The plug-in hybrids seem to be an attractive option in short and medium distance trips, mainly from 2030 onwards, because they comply with the standards and for shorter trips are not significantly more expensive in terms of total transport costs than alternative based on ICEs. Consumers travelling mostly in urban areas and only rarely travelling over long distance choose plug-in hybrids in this scenario context while not facing range limitations with that choice in seldom longer distance trips. Among the plug-in hybrids, double engine cars with range extender is seen in the results as an attractive option. The sensitivity analysis and iterations performed by changing the levels of the CO_2 regulation has shown that in the context of the dominant biomass case, ICE's energy efficiency improvements and biofuels (because of availability issues) cannot alone deliver the required emission reduction by 2050. The CO_2 regulation needs to be reduced by 2050 at levels which push grid-charged cars enter the market. Among such grid-charged cars the plug-in hybrids are likely to be the preferred choice in the long term, according to the model results.

The limited progress in the techno-economic performance of batteries limits substantially the share of pure electric vehicles (BEVs) which fail to compete with plug-in hybrids. The BEVs still maintain some role but the cost and range limitations allow for market penetration only in a limited share of short trip lengths.

Table 34: Stock of passenger cars and LDVs in the dominant biomass case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	87.6	86.6	48.0	16.0	-39.6	-72
Gasoline Conventional	150.4	129.5	80.6	23.2	-69.9	-127
Hybrid	0.0	29.8	74.4	52.1	74.4	52
LPG and CNG	5.6	22.0	35.2	36.5	29.6	31
Ethanol car	0.0	0.1	2.2	5.8	2.2	6
Plug-in Hybrid	0.0	16.2	44.3	118.1	44.3	118
BEVs	0.0	0.1	9.2	51.6	9.2	52
FCEVs	0.0	0.0	1.2	12.1	1.2	12
Total	**243.6**	**284.4**	**295.0**	**315.5**	**51.4**	**72**

As can be seen in Table 34, the stock of ICE cars and LDVs is almost three time larger in 2050 than in the electricity dominant scenarios. In the stock of passenger cars and LDVs, methane and LPG vehicle reach approx. 35 million vehicles in 2030 and 36.5 million in 2050. On the contrary of the scenarios in the dominant electricity context the amount of methane and LPG vehicles does not decrease after 2030, but stays constant and even rises slightly. The CO_2 standards that are not as strict as in the dominant electricity scenarios allows for continued use of these vehicle technologies and fuels. The complementary role of these fuels in achieving emission reductions does not remain in the mid-term but continues throughout the projection period.

Table 35: Stock of passenger cars and LDVs of age less than 4 years, in the dominant biomass case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	48.5	26.3	18.4	6.1	-30.1	-42.4
Gasoline Conventional	67.0	42.3	32.4	8.4	-34.5	-58.6
Hybrid	0.0	26.1	34.5	21.5	34.5	21.5
LPG and CNG	2.9	10.7	17.9	15.6	15.0	12.8
ethanol car	0.0	0.1	1.6	2.5	1.6	2.5
Plug-in Hybrid	0.0	15.2	22.0	51.6	22.0	51.6
BEVs	0.0	0.1	6.9	23.7	6.9	23.7
FCEVs	0.0	0.0	0.9	6.4	0.9	6.4
Total	**118.4**	**120.9**	**134.7**	**135.9**	**16.3**	**17.5**

New sales in 2030 are roughly 80% ICE's and 20% electric (exclusively plug-in hybrids). New sales in 2050 change in structure with ICE's representing 40% of total sales and electric cars covering 60% of the market. The market segment for electric cars is dominated by PHEVs also in 2050. BEVs represent only 5% of new car sales in 2030, but they start emerging in the market mainly after 2030, and achieve a share of 17.4% of new car sales in 2050. As explained above, the target towards high emission reduction by 2050, as reflected onto the CO_2 standards explains the penetration of electric vehicles in the long term.

7.4.5 Final energy demand

Final energy demand for passenger cars and LDVs decreases by 52% compared to 2005 levels, but is higher than the dominant electricity scenarios. The battery success case with CO_2 standards has 45% less energy consumption than the biomass scenario with CO_2 standards. The decrease in energy demand is due to the use of more efficient vehicles compared to 2005 levels; the reduced share of highly efficient BEVs in the stock increases overall energy demand compared to the dominant electricity scenarios.

Table 36: Final energy demand of passenger cars and LDVs by delivered form in the dominant biomass case with CO_2 standards

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Liquid Fuels	183.4	156.7	115.7	57.7	-67.7	-125.6
Gaseous Fuels	5.0	15.3	22.6	18.3	17.6	13.3
Liquefied hydrogen	0.0	0.0	0.3	2.5	0.3	2.5
Electricity	0.0	1.2	3.5	11.8	3.5	11.8
Total	**188.4**	**173.2**	**142.1**	**90.3**	**-46.3**	**-98.1**

Liquid fuels represent 64% of the delivered fuel, but the amount is almost equally divided between oil products and biofuels which account for 35.1Mtoe and 34.4Mtoe respectively. Although this scenario does not reduce oil product demand as much as the dominant electricity cases that reach an oil demand of approx. 24Mtoe, the reduction from 2005 values of approx. 186Mtoe is drastic and implies that private passenger vehicles reduce their dependence on oil products substantially. In the scenario both biofuels in blended and in pure form make large inroads; by 2050 pure biofuels represent about 10% of the total demand from private passenger fuels; whereas blended forms represent approx. 25% of final energy demand.

Table 37: Final energy demand of passenger cars and LDVs by fuel type in the dominant biomass case with CO_2 standards

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Oil products	186.2	151.7	106.2	35.1	-80.0	-151.1
Natural Gas	0.5	3.8	7.8	6.1	7.3	5.6
Biomass	1.7	16.4	24.4	34.4	22.7	32.7
Hydrogen	0.0	0.0	0.3	2.9	0.3	2.9
Electricity	0.0	1.2	3.5	11.8	3.5	11.8

Total	**188.4**	**173.2**	**142.1**	**90.3**	**-46.3**	**-98.1**

Methane gas as considered in the model has three components: natural gas, biogas and in later years hydrogen. Although the demand for natural gas which rises to 8Mtoe in 2030 declines at 6Mtoe by 2050, the demand for methane gases only decreases very slightly to 2050; the natural gas is substituted by biogas and is blended with hydrogen (produced via electrolysis, hence being decarbonised) thus reducing the specific emissions of the fuel. The improvements in the other technologies and the less strict CO_2 standards do not drive methane gas technology out of the market in the biomass context, as was the case in the dominant electricity scenarios.

7.4.6 What if energy efficiency standards were applied instead of CO_2 standards?

If energy efficiency standards were implemented instead of CO_2 standards, the main beneficiary technology would be hybrid vehicles according to model projections. Hybrid technologies cannot compete under CO_2 standards due to the remaining higher tailpipe emissions, but do enter the market under energy efficiency standards.

It is reminded at this point that the labels for the vehicles for the application of the CO_2 standards are calculated as implemented today; labels are determined as if the vehicles were running on gasoline or diesel and not on biofuels; this is because it cannot be determined beforehand whether a consumer in the presence of a flexible fuel vehicle will choose an oil based fuel or a biofuel. Within the model projections this assumption has been maintained throughout; if compulsory higher blends of biofuels are enforced, it could be discussed that the CO_2 label should be calculated based on blended fuel, in which case the results of the dominant biomass scenario with CO_2 standards would suggest a lower share of plug-in hybrid cars after 2030 than the projections presented above.

Table 38: Stock structure of private cars and LDVs in the dominant biomass case with CO_2 and energy efficiency standards

	2030		2050	
(million vehicles)	CO2 standards	Efficiency standards	CO2 standards	Efficiency standards
BEVs	9	10	52	45
Plug-in Hybrids	44	45	118	90
FCEVs	1	1	12	9
LPG and CNG	35	34	36	24
Conventional and Hybrids	205	204	97	149
Total	**295**	**294**	**315**	**316**

The switch from CO_2 to energy efficiency standards would therefore allow under the dominant biomass context for hybrid ICE technology to preserve a strong position in the market in the long term. Final energy demand would be higher due to the use of hybrids instead of PHEVs, but the additional fuel would almost entirely be composed by biofuels. Under energy efficiency standards the results show the highest contribution of biofuels among all scenarios. The lower capital costs of the hybrids compared to the PHEV being more attractive would help limiting cost increases in this transport sector scenario.

In other words, it seems, according to the model results, that the energy efficiency standard is more convenient in the dominant biomass case because of allowing for a higher variety of technologies to be maintained in the market, of lower costs and a decarbonisation process less depending on grid-charging.

7.4.7 Main results: freight and public road transport

The limited developments in fuel cells and battery based vehicles imply that freight and public transport remain dependent to the greatest extent on conventional ICEs and hybrids.

Table 39: Stock of HDVs, buses and coaches in the dominant biomass case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	8.6	10.1	7.2	4.8	-1.4	-3.7
Hybrid	0.0	0.4	4.0	6.1	4.0	6.1
LPG and CNG	0.0	0.1	0.3	0.9	0.3	0.9
Electric	0.0	0.0	0.1	0.7	0.1	0.7
Fuel Cell	0.0	0.0	0.0	0.2	0.0	0.2
Total	**8.6**	**10.6**	**11.7**	**12.8**	**3.1**	**4.2**

The penetration of battery electric vehicles is limited to the year 2050 when they reach a share of 5.9%; the share of fuel cell vehicles does not reach 2%. As was the case in the dominant electricity scenarios these kinds of vehicles only penetrate in urban areas and for trips where range limitations do not represent a barrier. The penetration of these vehicles is more limited than in the dominant electricity scenarios due to the limited progress regarding the techno-economic performance of these technologies.

Heavy duty vehicles see a decrease in final energy demand of 22% by 2050 compared to 2005; efficiency gains[48] assuming frozen technology at 2005 levels for heavy duty are of 63% in 2050 (see Figure 16). The large reduction in oil consumption is due to the large scale substitution with biofuels mainly biodiesel, methane from biogas and DME; biodiesel and biogas blends in diesel and methane respectively also attain a considerable share. Biodiesel is the most important biofuel in road freight transport as its consumption increases from 18 Mtoe in 2030 to approx 37 Mtoe in 2050. For buses and coaches the efficiency gains compared to frozen technologies at 2005 levels are 52%.

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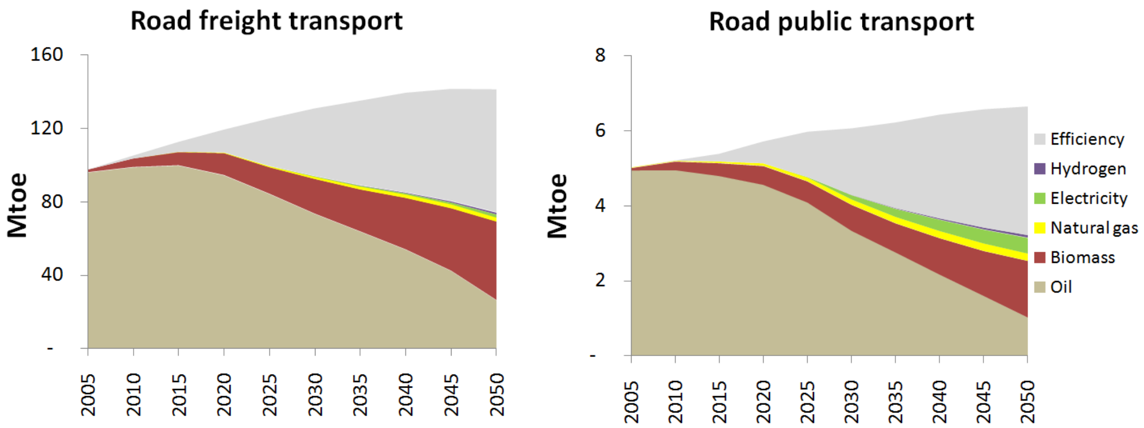
[48] Efficiency gains are defined as the additional energy needed in order to fulfil the activity by assuming that energy per activity unit remained constant at the levels of 2005

Figure 16: Energy consumption incl. Efficiency gains compared to 2005 levels in the dominant biomass scenario



7.5 “Renew” context

The transition cases presented above attempt to analyse the conditions under which induced technical change can lead to a transformation of the EU transportation system towards a dominant paradigm (electrification or biofuels). They depend crucially on favourable developments of specific key technologies: the battery success case hinges on the success of commercialisation of improved batteries in terms of energy density, costs, lifetimes, safety and charging speed; the fuel cell success case additionally on drastic cost reductions in fuel cell stack and system costs, while the dominant biomass case depends strongly on cost reductions of 2nd generation biofuels and technical improvements of ICEs.

In the previous scenarios it has been shown that batteries and fuel cells or extreme improvements in the efficiency of conventional ICEs and hybrids could provide a sustainable future in the transport sector if the techno-economic performances improve as expected.

The "Renew" context assumes parallel development of the required infrastructures for all alternative fuels assessed in this study. It is assumed that research and development will take place on a much broader front allowing all the technologies to develop but not to the same levels as in the “dedicated”- one paradigm scenarios. The scenario is therefore constructed to be less dependent on the progress of one technology alone.

Based on the uncertainty related to battery and fuel cell technology development even for the "Renew" context, different technology assumption sets were adopted: one with optimistic battery development ("Renew" Battery success case – RBS) and one with additionally more optimistic fuel cell development ("Renew" fuel cell success case – RFCS).

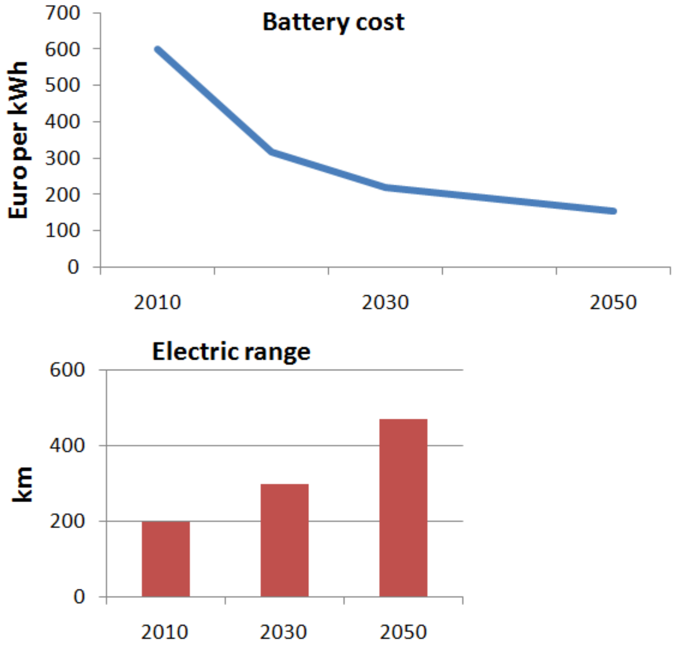
7.5.1 Technology assumptions

R&D effort is assumed to be more evenly distributed between the various technological options. This means somewhat slower improvements than those underpinning target technologies in the single paradigm scenarios. Technologies are therefore assumed not to improve as much as in the optimistic development cases, however still at a considerable pace. On the other hand technological improvement is considerable and on a much wider front.

As details about the technology options were presented in the one fuel paradigm cases only a summary of the assumptions is presented here for both variants.

In the variant with optimistic battery technology development ("Renew" Battery success case – RBS), the cost of the cheapest battery reaches 155 €/kWh in 2050 as shown in Figure 17. The specific energy consumption assumed for battery electric cars is similar to that assumed in the battery success case and complies with the literature (Safarianova 2011) and (Offer, et al. 2011). The driving ranges assumed vary from 300 to nearly 500km for cars in the long-term horizon depending on their battery size.

Figure 17: BEVs' characteristics development in the "Renew" battery success case



In the variant with optimistic fuel cell technology development ("Renew" fuel cell success case – RFCS) the hydrogen fuel cell technologies will develop along optimistic lines taking advantage of the broader spectrum of R&D development but not at the same extent of fuel cell success case as discussed in section 7.3. Fuel cell stack cost reaches 63 €/kW by 2020 and further decreases to 44€/kW and 32€/kW by 2030 and 2050 respectively. Such development is in the spectrum of recent studies (McKinsey 2010).

7.5.2 Development of fuel distribution infrastructure

In both "Renew" cases parallel infrastructures are assumed to develop. Refuelling stations with different types of liquid and gaseous fuels as well as hydrogen are assumed to become widely available; recharging stations for electric vehicles are assumed to develop both in urban and inter-urban areas as in the dominant electricity context. The "Renew" scenario-cases ensure against the more limited progress of a technology as adequate infrastructure for another alternative fuel/technology option is also assumed to develop. It must be noted, that the study did not attempt to optimise the extent of deployment of the refuelling infrastructures which ideally should depend on the market shares that the various fuels get in this "Renew" scenario, if a perfect anticipation assumption was made. Instead, the scenario design assumes preference in favour of developing all parallel infrastructures in order not to obstruct deployment of fuels/technologies, even if some of them are poorly used.

7.5.3 CO_2 and energy efficiency standards

As for all scenario-cases the policies assumed are those found in Table 13. The level of the CO_2 and energy efficiency standards implemented in the "Renew" cases, as needed to evolve over time to deliver the emission targets, can be observed in Table 40.It is reminded that two alternative scenario-cases were quantified each implementing one of the two candidate regulations.

Table 40: Implementation of CO_2 and energy efficiency standards in the "Renew" battery and fuel cell success cases

Renew battery success

CO_2 standards (gCO_2/km)	**2020**	**2030**	**2040**	**2050**
Passenger cars	95	72	28	20
LDVs	135	110	62	55
2wheelers	70	50	20	8

Energy efficiency standards (Litres of gasoline equivalent per 100km)	**2020**	**2030**	**2040**	**2050**
Passenger cars	6	3.7	2.2	1.8
2wheelers	5	3.8	1.6	0.4
LDVs	8	5	3	1.9
HDVs	28	23	18	15.5
Buses	20	18	14	13

Renew fuel cell success case

CO_2 standards (gCO_2/km)	**2020**	**2030**	**2040**	**2050**
Passenger cars	95	72	28	20
LDVs	135	110	62	55
2wheelers	70	50	20	8

Energy efficiency standards (Litres of gasoline equivalent per 100km)	**2020**	**2030**	**2040**	**2050**
Passenger cars	6	3.7	2.4	1.9
2wheelers	5	3.8	1.6	0.4
LDVs	8	5	3	1.7
HDVs	28	23	18	15.5
Buses	20	18	14	13

7.5.4 Main results: passenger cars and LDVs

The techno-economic progress at lower levels than the single-paradigm scenarios but still very optimistic leads to scenario results that are similar to those of the dominant electricity scenarios.

In the "Renew" case with battery success the stock of vehicles is dominated by BEVs and PHEVs in 2050, which as was the case in the dominant electricity battery success case is complemented by small amounts of FCEVs and a remaining share of conventional ICEs and hybrids.

Table 41: Stock of passenger cars and LDVs in the "Renew" battery success case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	87.6	85.4	42.1	5.9	-45.5	-81.7
Gasoline Conventional	150.4	127.5	67.4	6.8	-83.1	-143.7
Hybrid	0.0	27.0	65.9	23.3	65.9	23.3
LPG and CNG	5.6	22.5	34.7	15.0	29.1	9.4
Ethanol car	0.0	0.1	1.1	1.1	1.1	1.1
Plug-in Hybrid	0.0	18.5	53.2	90.8	53.2	90.8
BEVs	0.0	2.5	27.8	149.3	27.8	149.3
FCEVs	0.0	0.5	3.4	32.5	3.4	32.5
Total	**243.6**	**284.1**	**295.5**	**324.6**	**51.9**	**81.0**

The "Renew" fuel cell success scenario also sees a structure of the stock that resembles the dominant electricity with fuel cell success scenario; FCEVs penetrate the market with a considerable share, but the share of grid-connected vehicles (BEVs and PHEVs) is larger, although their share is more limited than in the battery success case.

Table 42: Stock of passenger cars and LDVs in the "Renew" fuel cell success case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	87.6	84.8	40.7	7.2	-46.8	-80.4
Gasoline Conventional	150.4	125.9	64.6	8.7	-85.8	-141.8
Hybrid	0.0	25.2	59.3	25.4	59.2	25.4
LPG and CNG	5.6	22.4	33.1	17.7	27.5	12.2
Ethanol car	0.0	0.1	0.9	1.2	0.9	1.2
Plug-in Hybrid	0.0	16.9	45.0	66.3	45.0	66.3
BEVs	0.0	2.3	23.9	97.4	23.9	97.4
FCEVs	0.0	6.3	29.1	108.6	29.1	108.6
Total	**243.6**	**283.9**	**296.7**	**332.6**	**53.1**	**89.0**

The larger availability of infrastructure leads to a higher penetration of methane and LPG vehicles, the share of which as was the case in the dominant electricity scenarios declines substantially after 2030; methane and LPG technologies penetrate the market in the medium term but are driven out of the market by the more efficient and less emitting BEVs, PHEVs, and FCEVs.

The new vehicle market also strongly resembles that of the dominant electricity scenarios, the large availability of infrastructure from early stages allows for a large variety of technology types in 2030, with are consistent with the 2050 developments.

7.5.5 Final energy demand

Final energy demand for passenger cars and LDVs due to the slightly more limited progress of highly efficient BEVs is a bit higher in the "Renew" battery success case compared to the dominant electricity battery success case. In the fuel cell case the difference in final energy demand is more limited.

Table 43: Final energy demand of passenger cars and LDVs by fuel type in the "Renew" battery success case with CO_2 standards

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Oil products	186.2	149.0	102.0	25.4	-84.2	-160.8
Natural Gas	0.5	4.0	8.4	2.5	7.9	2.0
Biomass	1.7	16.1	17.3	10.7	15.6	9.0
Hydrogen	0.0	0.1	0.8	7.0	0.8	7.0
Electricity	0.0	1.7	6.1	18.5	6.1	18.5
Total	**188.4**	**171.0**	**134.7**	**64.1**	**-53.7**	**-124.3**

Table 44: Final energy demand of passenger cars and LDVs by fuel type in the "Renew" fuel cell success case with CO_2 standards

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Oil products	186.2	146.2	95.3	25.5	-90.9	-160.7
Natural Gas	0.5	3.9	8.1	3.1	7.6	2.6
Biomass	1.7	15.7	16.0	10.4	14.3	8.7
Hydrogen	0.0	1.7	6.5	20.9	6.5	20.9
Electricity	0.0	1.6	5.2	12.3	5.2	12.3
Total	**188.4**	**169.2**	**131.1**	**72.2**	**-57.3**	**-116.2**

In the "Renew"-battery success case oil is still the fuel with the highest share, but in absolute terms it only amounts to 25Mtoe in 2050; oil consumption reduces by 86% between 2005 and 2050. The high share in final energy demand is due to the high efficiency of BEVs and PHEVs compared to ICEs. Also in the "Renew"-fuel cell success case oil demand reduces drastically to 26Mtoe in 2050.

Biomass final energy demand increases in both cases in early stages, due to the renewable obligations and biomass demand for passenger cars and LDVs peaks between 2020 and 2030. After that the penetration of electricity and hydrogen reduces the demand for liquids including biomass.

Natural gas demand is higher than in the corresponding scenarios of the dominant electricity; the higher availability of infrastructure increases its market penetration. The development of the battery based and fuel cell based technologies, together with the strict CO_2 standards, is nonetheless sufficient to drive methane and LPG cars out of the market.

7.5.6 What if energy efficiency standards were applied instead of CO_2 standards?

The introduction of energy efficiency standards instead of the CO_2 standards lead to similar effects as those observed in the context of the dominant electricity scenarios.

Table 45: Stock of private cars and LDVs in the "Renew" battery success case with CO_2 and energy efficiency standards

	2030		2050	
(million vehicles)	CO2 standards	Efficiency standards	CO2 standards	Efficiency standards
BEVs	28	29	149	149
Plug-in Hybrids	53	54	91	127
FCEVs	3	3	33	7
LPG and CNG	35	31	15	2
Conventional and Hybrids	176	177	37	48
Total	**296**	**294**	**325**	**332**

Table 46: Stock of private cars and LDVs in the "Renew" fuel cell success case with CO_2 and energy efficiency standards

	2030		2050	
(million vehicles)	CO2 standards	Efficiency standards	CO2 standards	Efficiency standards
BEVs	24	25	97	123
Plug-in Hybrids	45	47	66	114
FCEVs	29	30	109	43
LPG and CNG	33	31	18	2
Conventional and Hybrids	166	163	42	51
Total	**297**	**296**	**333**	**333**

Energy efficiency standards have a crowding out effect and the only remaining technologies are the highly efficient grid connected vehicles- BEVs and PHEVs. As was the case also in the other scenarios, in the battery success case this effect is almost complete, whereas in the fuel cell success case the better techno-economic characteristics of the fuel cell vehicles allow this technology to maintain a limited market share.

7.5.7 Main results: freight and public road transport

Electric and fuel cell vehicles enter the market more limitedly due to the lower techno-economic progress achieved in the "Renew" scenarios compared to the electricity scenarios; nonetheless their penetration is higher than in the biomass scenarios.

Table 47: Stock of HDVs, buses and coaches in the "Renew" battery success case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	8.6	10.1	7.0	4.4	-1.5	-4.2
Hybrid	0.0	0.4	4.0	5.6	4.0	5.6
LPG and CNG	0.0	0.1	0.4	1.3	0.4	1.3
Electric	0.0	0.0	0.2	1.0	0.2	1.0
Fuel Cell	0.0	0.0	0.0	0.2	0.0	0.2
Total	**8.6**	**10.6**	**11.6**	**12.6**	**3.1**	**4.0**

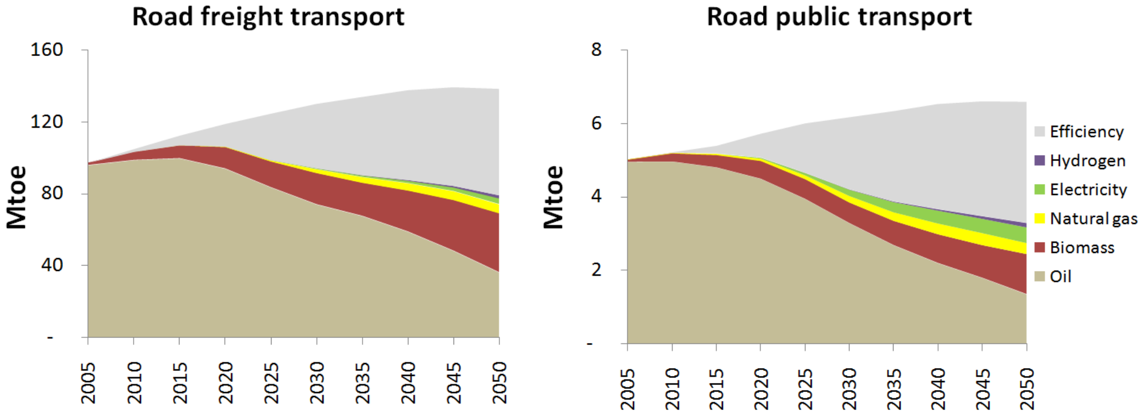
Table 48: Stock of HDVs, buses and coaches in the "Renew" fuel cell success case with CO_2 standards

(million vehicles)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	8.6	10.1	7.0	4.1	-1.6	-4.4
Hybrid	0.0	0.4	4.0	5.3	4.0	5.3
LPG and CNG	0.0	0.1	0.4	1.4	0.4	1.4
Electric	0.0	0.0	0.2	0.9	0.2	0.9
Fuel Cell	0.0	0.0	0.0	0.9	0.0	0.9
Total	**8.6**	**10.6**	**11.6**	**12.7**	**3.1**	**4.1**

Final energy demand is higher in the "Renew" scenarios due to the lower progress in energy efficiency of conventional ICEs and hybrids and the lower penetration of electric and fuel cell vehicles. Energy efficiency gains compared to frozen technology at 2005 levels are 42% in 2050 for freight transport and 50% for public transport; these values in the dominant electricity battery success scenario were 48% and 57% respectively.

Due to the higher availability of infrastructure and stronger development of biofuels final energy demand for freight and public transport for biofuels increase compared to the dominant electricity scenarios.

Figure 18: Energy consumption incl. Efficiency gains compared to 2005 levels in the "Renew" battery success case



8 What are the effects of CO_2 versus Energy Efficiency standards in driving deployment of alternative fuel-technologies?

In all cases considered within the CTS study further investigation was conducted on the effects of the implementation of different regulatory frameworks; in the cases analysed, CO_2 or energy efficiency standards were imposed as alternative possibilities. Both standards apply on a TTW basis as is the case with the current CO_2 standard regulation. The CO_2 standards set a constraint on the average tailpipe CO_2 emissions of newly registered vehicles, while energy efficiency standards would set a constraint on their average onboard efficiency.

The comparison of the modelling results of different cases shows various interesting issues related to the implementation of CO_2 versus energy efficiency regulations in the road transport sector.

CO_2 standards favour technologies which use energy carriers with low direct CO_2 emissions (therefore the tank-to-wheel emissions), such as electric vehicles, both fuel cell and battery-based. CO_2 standards penalise the carbon content of the energy carrier used for vehicle propulsion; therefore gaseous fuels and carbon free energy carriers such as electricity and hydrogen, penetrate more easily under such standards. When the CO_2 standards become stricter over time, to deliver the strong reductions necessary to achieve decarbonisation, gaseous fuels are gradually pushed out of the market to the benefit of FCEVs and BEVs; for this to occur a strong reduction in the costs of these technologies is also essential.

Energy efficiency standards favour technologies that have high tank-to-wheel energy efficiency. Strict energy efficiency standards favour efficient technologies such as BEVs or plug-in hybrids, but can hinder wide penetration of FCEVs in the long-term. BEVs and plug-in hybrids (especially those with high pure electric mileage provided) are more efficient than FCEVs; onboard efficiency of FCEVs is lower than BEVs due to the additional onboard transformation process (i.e. the fuel cell). In the fuel cell success case with implementation of energy efficiency standards despite the breakthrough in fuel cell technology development, the share of FCEVs deviates substantially from the fuel cell success case with CO_2 standards in which FCEVs dominate the car market by 2050.

LPG and methane cars enter the market more easily under a CO_2 regulation scheme (except if the regulation is very strict) as they are low emitting energy carriers. CO_2 standards applied in the mid-term period (2025-2035) encourage the penetration of such vehicles, as the standards are rather moderate during that period of time; in the cases analysed where energy efficiency standards were applied over the same period the share of LPG and methane cars was found lower, than with the CO_2 standards. Beyond 2035, as stricter CO_2 regulations apply, the shares of LPG and methane cars diminish as cleaner technologies/fuel options arise (e.g. BEVs and FCEVs), in particular in the cases where strict CO_2 standards are combined with strong decreases in the costs of BEV and FCEV technologies.

As far as the CO_2 label is concerned, there is no distinction in the model between vehicles running on fossil fuels or vehicles running with fungible biofuels, as it cannot be determined a priori whether a user will tank exclusively biofuels as this will depend on cost and availability considerations. Thus these vehicles all have the labels, both for energy efficiency and for CO_2 standards, as if they were running on fossil fuels. This is an implementation issue for the regulation which is crucial for bio-energy (blended with oil) using cars in case a CO_2 standard applies. If the blending proportions were fixed by standards, then the label of such cars could be adapted and so facilitate their market penetration. If the average blending is a result of consumer choice (with different outlets in service stations), then it is difficult to adapt the car label.

The results show, that in the dominant biomass case, energy efficiency standards are more relevant in order to shift towards more efficient ICE conventional technologies and as a result to use biofuels in a more rational way. Additionally, fuel quality or WTW emissions regulations are important as complements of the energy efficiency standards, in order to ensure the uptake of fuels with low overall carbon emissions. CO_2 standards can only be set at a moderate level in the context of the dominant biomass case; as it is assumed for this case that cost and performance of electric vehicles improves less than expected, setting strict CO_2 standards would penalise the market unnecessarily; hence a regulation opting for CO_2 standards is less effective in the dominant biomass case compared to the other cases. On the contrary, regulation opting for energy efficiency standards can ensure the development of improved technologies for ICE and hybrids, thus allowing for less energy consumption and a more efficient use of biofuels with limited availability.

Table 49: Competitive advantage of different technologies under the analysed regulatory frameworks[49]

		Moderate CO_2 standards (> 30gCO_2/km)	**Strict CO_2 standards (<30gCO_2/km)**	**Moderate Energy Efficiency standard (>2.4l/100km)**	**Strict Energy Efficiency standard (<2.4l/100km)**
BEV		++	+++	++	+++
FCEV		++	+++	++	-
PHEV[50] **(all fuels)**	High-range	++	++	++	++
	Mid-range	++	+	++	+
	Low-range	++	-	++	-
Hybrids (all fuels)		+	-	+	-
Conv. ICE	Gasoline/ diesel	-	-	-	-
	CNG	+	-	-	-
	LPG	+	-	-	-

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[49] The amount of "+" indicate the competitive advantage of a technology relative to the others; a "-" indicates that the technology has no competitive advantage.

[50] High range: the electric range is approx. 100km; mid-range: the electric range is around 50-80km; low-range: 20-40km.

In summary it can be tentatively concluded that to achieve high decarbonisation of the transport sector, strict standards are needed; either CO_2 or energy efficiency standards. Energy efficiency standards are fuel neutral, but if set at a very strict level they tend to limit the penetration of FCEV vehicles, as can be deduced from the results of the scenario assuming fuel cell success and energy efficiency standards. BEVs are not penalised by any regulatory option examined, as for FCEVs the main barrier to their market penetration is the development of the technologies (batteries or fuel cells) at lower costs. In the absence of cost-efficient electric vehicles, an energy efficiency standard is clearly the preferred regulatory option. In electricity domination context the results justify CO_2 standards as more appropriate, whereas in the biomass domination context the energy efficiency standards are more cost-effective.

9 Mid-term role of LPG and methane across the different cases

Natural gas and LPG vehicles represent technologies which are technically and commercially mature at present. Methane and LPG can be used in internal combustion engines (ICE). Methane currently is used in a compressed form (CNG) in road transportation (cars, LDVs and buses); methane in liquid form (LNG) is not used at present but could become commercially available for long-distance heavy transport. LPG is used mainly for passenger cars, light duty vehicles and buses, but its use for heavy duty vehicles is currently very limited.

Both LPG and CNG can also be used in bi-fuel cars[51] equipped with spark ignition engines[52]in combination with gasoline. Bi-fuel cars are equipped with two separate fuel tanks; one containing gasoline and the other LPG or CNG. The engine of the vehicles is operating with one fuel at a time and has the possibility to easily switch from one fuel to the other.

In several countries of the EU-27, as for example in Italy, Germany and Bulgaria, there exist today a considerable market of CNG cars with a significant number of filling stations. In Poland, Italy, Netherlands and Bulgaria there is also a considerable amount of LPG cars with adequate supporting network of refuelling stations.

LPG and natural gas are cleaner energy carriers than gasoline and diesel and therefore their CO_2 emissions are lower. According to published studies (Dudenhoeffer and Pietron 2010), the WTW GHG emissions from natural gas are 24% less than gasoline, 21% than diesel and 14% than LPG. CNG vehicles tailpipe CO, NO_x and PM emissions are also considerably lower than from diesel or gasoline cars; increased share of CNG vehicles therefore imply benefits for air quality.

For wider market penetration of natural gas and LPG powered cars, the refuelling network will need to expand considerably from today’s levels. Currently, despite the maturity of the technology, the number of refuelling stations is limited in Europe and this has proved detrimental to CNG and LPG vehicles sales. Refuelling stations network and fuel distribution infrastructure development seems to be the major key driver to deployment of alternative fuels such as LPG and natural gas in the car and LDV market. Natural gas for specific fleet vehicles like buses can be promoted independently through dedicated refuelling stations which are rather easy to implement. CNG buses emit less than ordinary diesel powered buses and therefore improve air quality particularly in urban areas.

LPG and methane could represent an interesting option to improve air quality and reduce emissions in a medium term horizon. But in the long term cleaner non fossil based fuels like electricity, hydrogen and biofuels will be required to achieve high decarbonisation targets. In

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[51] Bi-fuel cars operate in a different way from dual fuel (flexible fuel) cars. The latter store the fuels in one single tank and then the fuel blend is burned in the combustion chamber.

[52] Methane is already used in compression-ignition engines (diesel fuelled) of heavy duty vehicles.

order to shift towards LPG and methane in the mid-term period, infrastructure development poses the main barrier to overcome.

The above considerations are confirmed by the findings of the scenario projections and model simulations. Assuming some development of new refuelling infrastructure, natural gas and LPG are found to increase their share in the fuel mix in a medium-term horizon.

Table 50 shows the methane and LPG consumption in the transport sector in the dominant biomass and the battery success cases. LPG consumption in both cases increases to approx 16 Mtoe in 2030 mainly due to the penetration of LPG powered passenger cars. In the battery success case, LPG consumption decreases gradually after 2030 (8 Mtoe in 2050), as LPG cars fail to comply with the increasingly intense CO_2 standards. In the dominant biomass case where the intensity of the CO_2 standards is set at moderate levels, LPG consumption remains rather stable after 2030, reaching 14 Mtoe in 2050. The main consumers of LPG are the passenger cars and at a lesser extent the HDVs, the busses and the coaches.

Natural gas consumption increases to 10 Mtoe in 2030 in both scenarios; the main natural gas consumer is the private road transport sector. As was the case with LPG, natural gas consumption in the battery success case decreases after 2030 (4 Mtoe in 2050), whereas in the dominant biomass case it remains constant at 9 Mtoe in 2050. Strict CO_2 standards, as applied in the battery success case for the passenger cars, drive CNG cars out of the market.

Table 50: LPG and natural gas consumption in the transport sector in the dominant biomass and the battery success cases with CO_2 standards

	Battery success				
(Mtoe)	2005	2020	2030	2040	2050
LPG	5	12	15	11	8
Nat.gas	1	4	10	7	4

	Dominant Biomass				
(Mtoe)	2005	2020	2030	2040	2050
LPG	5	12	16	16	14
Nat.gas	1	4	9	10	9

Despite the substantial market inroads of methane and LPG vehicles, their market volume remains rather small.

Table 51 shows the evolution of the stock of LPG and CNG cars in the dominant biomass, the battery success and the "Renew" battery success cases.

The share of CNG cars in the total stock increases to 1.7% by 2020 and 3.9% by 2030 in the battery success case before decreasing in the long-term. In the dominant biomass case the market share reaches 1.7% by 2020 and further increases to 4.5% and 5.3% by 2030 and 2040 respectively. In the "Renew" battery success case the market share of CNG cars increases to 1.9% in 2020 and 4.3% in 2030; beyond 2030 the market share decreases. This projection of CNG car diffusion lies within the range mentioned in other published studies, as for example

(Dudenhoeffer and Pietron 2010) and (Future Transport Fuels 2010), which foresee a potential 5% market share of CNG by 2020.

Table 51: Stock of CNG and LPG cars in EU-27 in the dominant biomass, the battery success and the Renew battery success cases with CO_2 standards and their % share in the total stock of passenger cars

	Battery success									
(million cars)	2005	2020	2030	2040	2050	2005	2020	2030	2040	2050
LPG	5	14	16	10	5	2.3%	6.0%	6.7%	3.9%	1.7%
CNG	1	4	9	6	2	0.3%	1.7%	3.9%	2.3%	0.7%

	Dominant Biomass									
(million cars)	2005	2020	2030	2040	2050	2005	2020	2030	2040	2050
LPG	5	14	17	18	15	2.3%	6.0%	7.3%	7.5%	6.1%
CNG	1	4	11	13	12	0.3%	1.7%	4.5%	5.3%	4.6%

	Renew battery success									
(million cars)	2005	2020	2030	2040	2050	2005	2020	2030	2040	2050
LPG	5	15	18	10	6	2.3%	6.2%	7.5%	4.0%	2.2%
CNG	1	4	10	6	3	0.3%	1.9%	4.3%	2.5%	1.2%

The market share of LPG cars increases to 6% by 2020 and 6.7% by 2030 in the battery success case; beyond 2030 their market share decreases. In the dominant biomass case the share of LPG cars increases to 6% by 2020 and further increases to 7.3% and 7.5% by 2030 and 2040 respectively before reducing to 6.1% by 2050. As regards the "Renew" battery success case the market share of LPG cars reaches 6% by 2020 and 7.5% by 2030. The projection of future market shares of LPG cars seems to be similar to findings by other studies, such as (Future Transport Fuels 2010) and (Purwanto 2009).

Sensitivity analysis regarding the extent (density) of the refuelling infrastructure show that their market deployment in the medium term could be higher depending on the spatial density of the infrastructure, but their prospects for the longer term are less dependent on infrastructure but dependent on the deployment of cleaner vehicle types.

Comparing the modelling results of the battery success and the "Renew" battery success cases illustrate the role of refuelling infrastructure: the market shares of LPG and CNG cars in the former case are lower than in the latter, as it is assumed that multiple fuel infrastructures develop in the former case.

As discussed in other sections, CO_2 standards seem to favour market penetration of LPG and CNG cars, as long as their level remain moderate; strict energy efficiency standards are detrimental to LPG and CNG cars which are generally less efficient than the equivalent diesel ICEs.

10 Analysis by transport mode

10.1 Aviation

The level of detail of aviation sector in the PRIMES-TREMOVE Transport model is not as high and sophisticated as in the road transport sector. The PRIMES-TREMOVE transport model assumes five different categories regarding the distance of trips.

Modest changes have been observed across the cases regarding aviation activity. Table 52 shows aviation activity in the battery success compared to the Reference scenario. Beyond 2030 a slight decrease in the activity is observed in the battery success case compared to the Reference scenario; such decrease in activity reflects the effect of the ETS price.

Aviation distance classes (km)
< 500
500 - 1000
1000 - 1500
1500 - 2000
>2000

Table 52: Aviation activity

	Activity in Gpkm					Average annual percentage change		
	1990	2010	2020	2030	2050	1991-2010	2011-2030	2031-2050
Reference	317	577	814	1053	1388	3.04%	3.05%	1.39%
Battery success			819	1074	1309		3.16%	0.99%
Dominant biomass			819	1071	1294		3.14%	0.95%
Renew battery success			819	1074	1306		3.15%	0.98%

The model database includes a representation of energy efficiency possibilities and their costs in the aviation sector. These possibilities distinguish between measures which optimise logistics and perform moderate improvements in the aircrafts, and technologies which involve new designs and innovations for aircrafts and engines. The model does not include technologies that involve radically new concepts and has limited representations to measures and techniques that are proven and are mature with present knowledge.

As aviation is subject to ETS prices and most of the measures which optimise logistics and perform moderate improvements are cost-effective, the reference scenario projection shows considerable energy efficiency gains in aviation. The additional improvements in energy efficiency in the context of the emission reduction scenarios are limited.

Average specific energy consumption (final energy over activity) in the EU aviation[53] in the reference scenario is projected to reduce by 46% over the period 2006 to 2050, which implies

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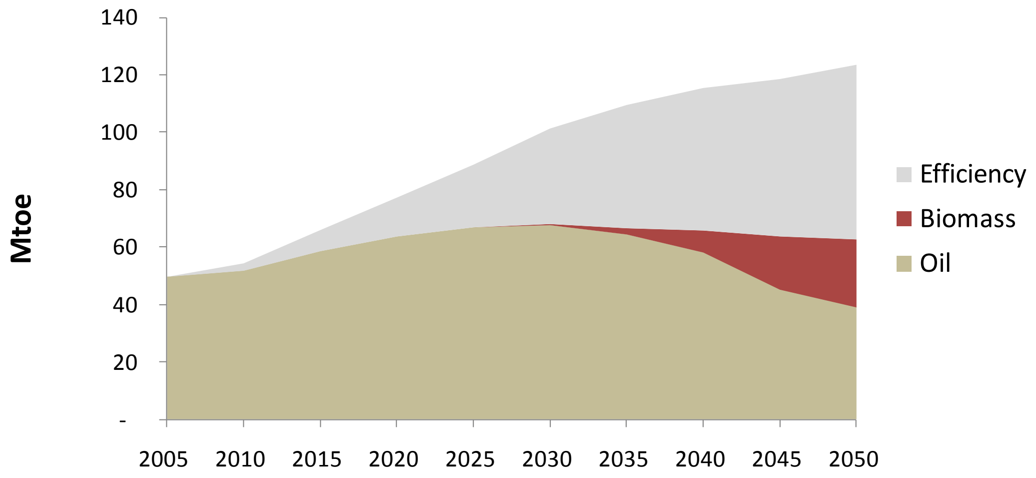
[53] Energy consumption in aviation follows Eurostat's energy balance conventions and correspond to fuel provision in EU airports irrespective of destination.

an average rate of energy efficiency improvement of 1.36% per year. The ETS prices as projected in the reference scenario are high compared to today's levels and drive the adoption of energy efficiency measures in aviation. The same average specific energy consumption in aviation reduces by 50% over the period 2006-2050 in the emission reduction scenarios, which means that the annual energy efficiency improvement is higher (i.e. 1.49% per year) in the emission reduction scenarios.

Final energy demand reaches in the emission reduction scenarios nearly 62 Mtoe by 2050 from 49.7 Mtoe in 2005 showing an increase of 24.7% (see Figure 19). The increase in activity is compensated by efficiency gains due to engine related and logistic improvements.

Figure 19: Energy consumption of aviation incl. Efficiency gains relative to 2005 in the battery success case



The main option for emission reduction in aviation is the blending of biofuels which add to the effects of energy efficiency improvements.

Biokerosene produced through 2nd and 3rd generation processes is assumed to be available after 2030 and in larger amounts beyond 2040. A significant share of biokerosene is assumed to be used and its share ranges between 38% and 43% with the latter appearing in the dominant biomass cases. The use of biokerosene allows for significant reduction in CO_2 emissions in the aviation.

10.2 Rail

The PRIMES-TREMOVE transport model distinguishes rail into freight and passenger; passenger rail is further split in slow and high speed and metro and tram. The model keeps track of the capital vintages and the evolution of the rail stock; two types of rail technologies are considered: locomotives and railcars, both running either on diesel or on electricity. High speed trains are considered those achieving speeds above 200km/hr and run on electricity.

Table 53 shows the evolution of passenger rail activity in the battery success scenario; regarding passenger rail activity the projections are similar in all emission reduction scenarios.

Table 53: Passenger rail activity disaggregated by mode in the battery success case

	Activity in Gpkm			Average annual percentage change		
	2010	2030	2050	2011-2030	2031-2050	2011-2050
Metro/tram	85	97	107	0.68%	0.50%	0.59%
High speed passenger trains	87	134	195	2.21%	1.88%	2.04%
Slow passenger trains	311	415	488	1.45%	0.82%	1.13%
Total	**482**	**646**	**790**	**1.47%**	**1.01%**	**1.24%**

Slow passenger rail holds the most important share of activity; high speed passenger rail gains significant share by 2050 while metro activity sees modest evolution. The overall passenger rail activity increases by 3% compared to the Reference scenario by 2050. Throughout the projection period there is an increase in activity and share of fast passenger trains. Whereas their share was around 17% in 2005 by 2030 fast trains represent a share of almost 25% in 2050; this increase in share goes to the detriment of the share of slow passenger train activity, although the activity of both continues to rise. Fast passenger trains increase their competitiveness throughout the time period due to increases in efficiency and the relative decrease in ticket costs compared to other transport modes.

Table 54: Freight rail activity

	Activity in Gtkm					Average annual percentage change		
	1990	2010	2020	2030	2050	1991-2010	2011-2030	2031-2050
Reference	526	440	525	579	652	-0.89%	1.38%	0.60%
Battery success			550	612	705		1.66%	0.71%
Dominant biomass			549	611	702		1.65%	0.70%
Renew battery success			550	612	708		1.66%	0.73%

Freight rail activity sees an increase compared to the Reference scenario by 8% in 2050. Such an increase in freight rail activity is foreseeable due to an increase in loading capacity of trains (higher train lengths) and reduction in operating costs. Additionally, higher train speeds and improved logistics reduce the time needed for the transportation of goods and as a result it has a beneficial impact on the generalised price of transportation[54]. Relative transportation costs, which are in favour of rail freight transportation, drive modal shifts in favour of rail in

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[54] The generalised price of transportation includes monetary and non-monetary costs. Monetary costs are the “out of pocket” costs which include fixed and variable costs. Non- monetary costs refer to the cost of time taking into account the value of time which differentiates according to the purpose of the trip.

the emission reduction scenarios. As expected, this has beneficial effects on energy efficiency and emissions.

Following the assumptions of the Reference scenario, rail is assumed to be almost entirely electrified beyond 2040; only small amounts of tracks remain "unelectrified" with limited activity; this trend is intensified in the emission reduction scenarios. The trend towards higher energy consumption driven by the increase in activity is compensated by the electrification of rail which is more energy efficient, implying that overall energy consumption for rail, both freight and passenger, after increasing in the mid-term while diesel is not yet fully phased out, decreases in the long-term when almost 100% electrification of rail is achieved as shown in Table 55. Beyond 2030 diesel is blended with small quantities of biodiesel.

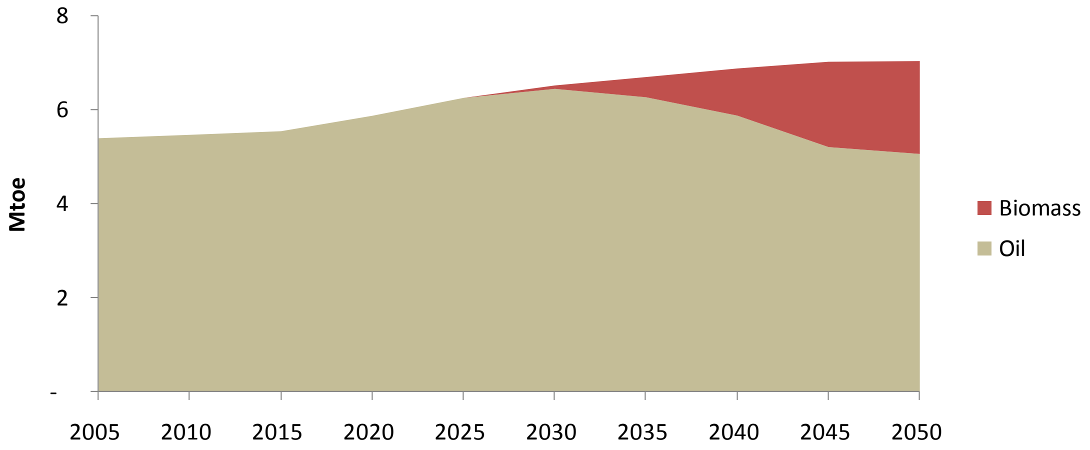
Table 55: Energy consumption of passenger and freight rail

(ktoe)	2005	2020	2030	2050
Electricity	6353	7967	8837	9287
Oil	3083	1869	1068	141
Biomass	0	46	22	51
Total	**9436**	**9882**	**9927**	**9479**

10.3 Inland navigation

Inland navigation of the PRIMES-TREMOVE model includes inland waterways and short sea shipping.

Figure 20: Energy consumption of freight and passenger inland navigation



Freight and passenger inland navigation consumption sees an increase of approx. 30% in 2050 compared to 2005 due to the increase in activity; the increase in efficiency is not sufficient to compensate for the increase in activity. Biodiesel share in the energy mix of IWW in the electro-mobility cases reaches a 27%, while in dominant biomass cases a much higher rate of biofuel use is projected with biodiesel and bioheavy representing 55% of final energy demand in inland navigation. It must be noted that the modelling detail for this sector is poor, mainly because of lack of data regarding the classification of vessels, ships and boats in size and trip purpose categories.

10.4 Development of international maritime shipping

The overall PRIMES model performs projection for bunker fuels but this sector is not included in the PRIMES-Tremove transport model.

Total emissions from shipping have been estimated by the IMO (IMO 2009) to amount to 1006MtCO_2 in 2006, the equivalent of 3.3% of global anthropogenic emissions (IMO 2009). Emissions from ships using EU ports, account for 31% of global shipping emissions (Faber, et al. 2009). All forecasts about maritime shipping emissions, expect emissions to rise in future; higher energy efficiency is not expected to compensate for the rise in demand for maritime transport, unless additional measures are adopted. The main driver for increase in maritime transport is the growth in international trade for goods driven by the increase in global trade and the dispersion of production and consumption locations.

Emissions in shipping can be influenced by altering the carbon content of fuels used, and by improving the operational and the ship technology efficiency.

The reduction of carbon content of fuel can only be tackled by switching to a fuel with lower carbon content; this option is very much dependent on the fuel price. Fuels currently used in shipping are low cost fuels, “cleaner” fuels are generally more expensive; as fuel costs make up a large amount of the variable costs of maritime transportation cheap alternatives need to be made available for a large scale uptake.

A number of both technical and operational options are available under currently available technological knowledge that could reduce emissions between 23 and 47% by 2030 (Faber, et al. 2009). The relative cost of these measures and therefore their uptake is strongly dependent on the fuel prices, but the limited implementation of the most cost-efficient measures still faces barriers such as lack of incentives, transaction costs and time lags (Faber, et al. 2009). Implementation of policy measures that would drive emission reduction depend on international agreements; see (DNV 2009), (Hobson, et al. 2007) and in the preliminary results of the project “Low Carbon Shipping: a Systems Approach”[55]; for example a cap and trade system would require global implementation. Command and control policies, including standards could also deliver significant progress in emission reduction.

10.5 Transport activity by transport mode

Although no policy-measures were explicitly modelled into the scenario design, due to changes in the average cost of transportation for each transport mode, as driven by changes in capital and variable costs, lead to modal shifts. Also the variations between scenarios are caused by the changes in the relative average cost of transportation between transport modes.

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[55] http://www.lowcarbonshipping.co.uk/

Table 56: Passenger and freight transport activity and the shares of the different transport modes in the different scenario-cases analysed[56]

		2005	Reference scenario		Dominant electricity			
					Battery success		Fuel cell success	
			2030	2050	2030	2050	2030	2050
Passenger transport activity	**Gpkm**	**6240**	**8386**	**9453**	**8195**	**9191**	**8197**	**9317**
Private Road	% shares	75.1	71.6	69.4	70.6	68.9	70.6	69.5
Public Road		8.4	7.7	7.3	7.8	7.7	7.8	7.5
Rail		7.4	7.7	8.1	7.9	8.6	7.9	8.4
Aviation		8.4	12.6	14.7	13.1	14.2	13.1	14.2
Inland Navigation		0.6	0.6	0.5	0.6	0.6	0.6	0.6
Freight transport activity	**Gtkm**	**2495**	**3438**	**3863**	**3374**	**3701**	**3372**	**3703**
Road	% shares	72.2	73.2	73.5	71.3	70.3	71.3	70.2
Rail		16.6	16.8	16.9	18.1	19.1	18.2	19.1
Inland Navigation		11.2	10.0	9.6	10.5	10.7	10.5	10.7

			Dominant biomass		Renew			
					Battery success		Fuel cell success	
			2030	2050	2030	2050	2030	2050
Passenger transport activity	**Gpkm**		**8163**	**8997**	**8182**	**9133**	**8202**	**9260**
Private Road	% shares		70.6	68.4	70.5	68.9	70.6	69.4
Public Road			7.8	7.7	7.9	7.5	7.9	7.4
Rail			7.9	8.9	7.9	8.7	7.9	8.4
Aviation			13.1	14.4	13.1	14.3	13.1	14.2
Inland Navigation			0.6	0.6	0.6	0.6	0.6	0.6
Freight transport activity	**Gtkm**		**3382**	**3705**	**3373**	**3667**	**3373**	**3683**
Road	% shares		71.5	70.4	71.3	69.8	71.3	70.0
Rail			18.1	18.9	18.1	19.3	18.2	19.2
Inland Navigation			10.5	10.6	10.5	10.9	10.5	10.8

Transport activity increases throughout the projection period in all scenarios. Passenger activity sees a slight modification in the shares compared to 2005 levels; the highest share growth is in aviation which increases considerably by over 5 percentage points compared to 2005 already in 2030 and only moderately beyond 2030. The increase up to 2030 is a result of lower energy prices (driven by the worldwide reduced energy prices which is part of the assumptions in the emission reduction scenarios) compared to the reference scenario; beyond 2030 the increase in ETS carbon taxes dominates and the effects of higher energy prices on activities is noticeable.

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[56] All the scenario cases presented here are with CO_2 standards.

The shares of private road transport (passenger cars, LDVs and motorcycles) decrease considerably due to the increased average costs of transportation: this increase is due mainly to the increased capital cost in the dominant electricity cases, whereas it is caused by the combination of higher fuel costs and higher capital costs in the dominant biomass scenario.

Freight transport also increases considerable throughout the projection period. The improvements in freight rail transportation caused by the increase in load capacity, higher speed and improved logistics leads to an increase in the share of rail in freight transportation and a consequent reduction of the other transportation modes. Changes in relative prices, which are marked in the emission reduction scenarios, also drive modal shifts in freight transportation in favour of rail and inland navigation.

Specific CO_2 emissions (i.e. emissions by unit of transportation activity) by transport mode decrease substantially throughout the projection period. Already in the Reference scenario efficiency improvements lead to substantial specific emission reductions which go down to 68gCO_2/pkm a 44% decrease compared to 2005; the emission reductions are driven by the moderate CO_2 standards implemented in the Reference scenario.

In 2030 all the scenarios quantified achieve almost the same specific emissions per unit of activity due to the fact that the level of the CO_2 standards is highly comparable. In the dominant electricity scenarios due to the market penetration of vehicles with zero tailpipe emissions and the strict CO_2 emission standards implemented, the specific emissions in private transport decrease substantially beyond 2030. By 2050 CO_2 emissions in the battery success case are 90% lower than 2005 emissions averaging 12gCO_2/pkm. The emissions are slightly higher in the dominant biomass scenario due to the lower share of zero tailpipe emission vehicles, but the use of biofuels implies that emissions remain at 19gCO_2/pkm, 58% above the dominant electricity with battery success, but still 84% below 2005 levels.

Table 57: Specific emissions of passenger cars and LDVs

	2005	2030		2050	
		gCO_2/pkm	Diff. to 2005	gCO_2/pkm	Diff. to 2005
Reference	121	80	-34%	68	-44%
Battery success		58	-52%	12	-90%
Dominant Biomass		59	-52%	19	-84%
Renew battery success		57	-53%	13	-89%

For public passenger transport the specific transport emissions also reduce substantially. Already in the Reference scenario substantial energy efficiency gains are projected which drive emission reduction at some extent. In the emission reduction scenarios, the specific CO_2 emissions reduce almost double than in the reference.

Already in 2030 the specific emissions in public passenger transport reduce considerably more than in the reference scenario and reach levels between 43% and 44% down from 2005 levels; this is due mainly to the additional energy efficiency improvements and the extensive use of hybrid vehicles.

By 2050 all the emission reduction scenarios show a decrease in emissions in public passenger transport exceeding 75% compared to 2005; beyond 2030 there is still extensive improvement in efficiency and further use of hybrids, but this is complemented by high shares of biofuels within consumption of liquid fuels. The highest reduction in specific emissions in this sector corresponds to the dominant biomass scenario where the share of biofuels is largest and the additional improvements in ICE compensate for the reduced share of battery based vehicles.

Table 58: Specific emissions of public passenger road transport (buses and coaches)

	2005	2030		2050	
		gCO_2/pkm	Diff. to 2005	gCO_2/pkm	Diff. to 2005
Reference	29	22	-24%	19	-35%
Battery success		16	-43%	7	-76%
Dominant Biomass		17	-43%	5	-83%
Renew battery success		16	-44%	7	-76%

Also in road freight transport the emission reductions are considerable already in 2030 and decrease even further in 2050. The improvements in conventional ICEs and hybrids substantially contribute to the lowering of emissions already in 2030 aided by the penetration of biofuels; in 2050 as was the case with public passenger road transport the reductions in road freight transport are lowest in the dominant biomass scenarios where the biofuels have the highest share.

Table 59: Specific emissions of freight road transport (HDVs and freight LDVs)

	2005	2030		2050	
		gCO_2/tkm	Diff. to 2005	gCO_2/tkm	Diff. to 2005
Reference	164	125	-23%	113	-31%
Battery success		94	-42%	45	-72%
Dominant Biomass		94	-42%	33	-80%
Renew battery success		96	-41%	47	-71%

Table 60: Specific emissions of aviation

	2005	2030		2050	
		gCO_2/pkm	Diff. to 2005	gCO_2/pkm	Diff. to 2005
Reference	279	188	-33%	151	-46%
Battery success		187	-33%	89	-68%
Dominant Biomass		187	-33%	81	-71%
Renew battery success		187	-33%	86	-69%

Also in aviation the specific emissions decrease considerably. Until 2030, as hardly any bio-kerosene is available by that date, the specific emissions are almost the same as in the Reference scenario, which is also due to cost effective technical and non-technical energy efficiency measures projected to be taken up at approximately the same levels already in the

Reference scenario. Beyond 2030, bio-kerosene is expected to penetrate the market driving significant emission reductions. Again, as was the case for public road transport and freight road transport the higher availability of bio-kerosene in the dominant biomass case lead the specific emissions in this scenario to be lowest.

Emissions per unit of activity for rail beyond 2030 are extremely low due to the high electrification rates assumed; further the use of biofuels additionally reduces the emissions of the remaining liquid fuels used.

11 Comparison of scenario projections

The current section provides a comparison of three representative cases and the Reference scenario. The study focuses on three main scenario contexts for the transport sector; the dominant electricity, the dominant biomass and the "Renew" context. All scenario variants, reflecting alternative assumptions about policies or technological developments are designed for each scenario-context. The scenario variants consider implementation of CO_2 standards or alternatively energy efficiency standards. Both for the dominant electricity and the "Renew" scenarios, two cases of technological development were quantified: one involving battery success and another involving additionally fuel cell success. In total ten scenario variants were quantified.

In order to provide comparative information about the modelling results, this section focus on the comparison of the following scenario cases:

- Battery success with CO_2 standards
- Dominant biomass with CO_2 standards
- "Renew" with battery as dominant technology with CO_2 standards

All three cases reduce energy demand compared to the reference scenario and involve substitutions towards lower carbon intensity. The reduction in energy demand is achieved through three main options: improvement of vehicle technologies, switch to energy carriers which enable significant energy efficiency gains and emission reduction and at a lesser extent reduction of activity and modal shifts. The latter are induced by the changes both in total transportation costs and in relative costs of transport modes.

11.1 Final energy demand

All scenarios reduce energy demand compared to the reference scenario (see Table 61), but at different levels depending on the prevailing paradigm.

Table 61: Final energy demand

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Reference	362	398	392	387	30	24
Battery success	362	371	325	220	-37	-142
Dominant Biomass	362	372	332	251	-31	-111
Renew battery success	362	369	324	228	-38	-134

Table 62: Average annual percentage change of GDP, final energy demand and CO_2 emissions

	Average annual percentage change		
	2011-2020	2021-2030	2031-2050
GDP	2.21%	1.74%	1.48%
Final energy demand			
Reference	0.65%	-0.15%	-0.07%
Battery success	-0.05%	-1.32%	-1.93%
Dominant Biomass	-0.03%	-1.14%	-1.38%
Renew battery success	-0.10%	-1.30%	-1.74%
CO2 emissions			
Reference	0.17%	-0.38%	-0.10%
Battery success	-0.68%	-2.08%	-4.30%
Dominant Biomass	-0.66%	-2.06%	-4.42%
Renew battery success	-0.75%	-2.05%	-4.26%

All three emission reduction cases show an impressive decoupling of energy demand and CO_2 emissions from GDP growth (see Table 62). Such a decoupling is seen also in the Reference scenario but at far less extent than in the three cases; the year 2020 seems to be the turning point, in the cases, towards an era of continuous decrease of energy demand compared to GDP. The decoupling of energy demand from GDP growth is slightly smaller in the dominant biomass scenario compared to the other two policy scenarios.

The dominant biomass case which relies on the continued use of ICE technologies (even though they are greatly improved), with shifts in fuel mix in favour of biofuels, shows the highest energy consumption. The battery success case shows the lowest total energy consumption due to the shift away from ICE technologies towards the more efficient battery electric powertrains. The "Renew" battery success case where the two paradigms coexist has an energy consumption which is in between the other two cases.

All cases achieve impressive reductions in demand for petroleum products: in the order of 70% less in 2050 and more than 20% less in 2030 compared both to 2005 and the reference scenario projection for 2050. The battery success and "Renew" battery success cases substitute oil mainly through electricity and biofuels and other alternative fuels at a lesser degree, whereas the dominant biomass case substitutes oil mainly through biofuels.

Table 63: Final energy demand for oil

(Mtoe)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Reference	352	359	346	339	-7	-14
Battery success	352	328	261	108	-91	-244
Dominant Biomass	352	329	264	104	-89	-249
Renew battery success	352	326	260	106	-93	-246

Table 64: Final energy demand for natural gas

(Mtoe)	2005	2020	2030	2050
Reference	1	1	1	1
Battery success	1	4	10	4
Dominant Biomass	1	4	9	9
Renew battery success	1	4	11	8

The emission reduction cases involve higher demand for natural gas especially in the medium term, i.e. between 2025 and 2035, which is supported by the timely development of the distribution infrastructure. The consumption of natural gas reduces after 2035 but remains in 2050 at a substantial level if compared to the past. In the battery success case though, the wide penetration of BEVs and the intensity of CO_2 standards on passenger cars leads to a higher reduction of natural gas consumption than in the other two main cases.

The form of the delivered fuels to consumers changes over time in all three emission reduction cases. All of them show a substantial decrease in the share of liquid fuels in favour of electricity and gaseous fuels and in the longer term liquefied hydrogen emerges. From a share of 90%, liquid fuels decrease to 73% in battery success case and to 79% in dominant biomass case by 2050.

Among the liquid and gaseous fuels the dominant biomass case represents the highest variety of different fuel types that will be available for the consumer, which goes together with the significant development of a variety of parallel refuelling infrastructure. This is also true in the "Renew" battery success case which in addition involves significant development of electricity recharging and hydrogen refuelling infrastructure in the long term. The lowest variety of fuel types, hence the lowest density of various parallel refuelling infrastructures is projected in the battery success case.

Driven by assumptions specific to the battery success case, this scenario involves the highest use of electricity in transportation. The results show that electricity consumption remains very significant also in the "Renew" battery success case which projects electricity demand for mobility to become 11.3% lower than the battery success case in 2050. This contrasts the dominant biomass case where electricity demand in mobility in 2050 is 36.5% lower than battery success case; nevertheless this is still 2.6 times higher electricity consumption compared to the reference scenario.

Table 65: Demand for electricity

(TWh)	2005	2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Reference	74	90	99	103	26	29
Battery success	74	110	187	421	113	347
Dominant Biomass	74	107	149	272	75	198
Renew battery success	74	114	184	376	110	302

Table 66: Demand for hydrogen

(Mtoe)	2030	2050

Reference	0	0
Battery success	1	11
Dominant Biomass	0	4
Renew battery success	1	9

The dominant biomass case involves significant development of methane from biogas both blended in gas distribution grids and as independent distribution as pure biogas. This contrasts the "Renew" battery success and the battery success cases which involve hydrogen blended in the natural gas distribution grid, while biogas at smaller quantities is still distributed through a dedicated distribution infrastructure. LPG is also making significant inroads in all three cases as a medium term solution peaking close to 2030 and reducing afterwards.

Table 67: Demand for Biofuels

	Renew battery success			
(Mtoe)	2005	2020	2030	2050
Biogasoline	0.6	7.9	8.9	6.7
Biodiesel	2.5	21.1	26.8	37.3
DME	0.0	0.0	0.4	3.3
Bio Kerosene	0.0	0.0	0.4	24.8
Bio Heavy	0.0	0.0	0.0	0.2
Biogas	0.0	0.0	0.1	0.4
Total	**3.1**	**29.0**	**36.5**	**72.8**

	Battery success			
(Mtoe)	2005	2020	2030	2050
Biogasoline	0.6	8.0	9.2	6.3
Biodiesel	2.5	21.0	27.1	30.0
DME	0.0	0.0	0.0	0.0
Bio Kerosene	0.0	0.0	0.4	23.6
Bio Heavy	0.0	0.0	0.0	0.2
Biogas	0.0	0.0	0.0	0.7
Total	**3.1**	**29.0**	**36.7**	**60.7**

	Dominant Biomass			
(Mtoe)	2005	2020	2030	2050
Biogasoline	0.6	8.1	10.7	19.6
Biodiesel	2.5	21.4	32.5	55.8
DME	0.0	0.0	1.0	7.4
Bio Kerosene	0.0	0.0	0.4	26.9
Bio Heavy	0.0	0.0	0.0	0.3
Biogas	0.0	0.0	0.9	1.6
Total	**3.1**	**29.5**	**45.5**	**111.6**

	Reference			
(Mtoe)	2005	2020	2030	2050
Biogasoline	0.6	8.6	10.7	11.4
Biodiesel	2.5	21.4	25.7	26.2
DME	0.0	0.0	0.0	0.0
Bio Kerosene	0.0	0.0	0.0	0.0
Bio Heavy	0.0	0.0	0.0	0.0
Biogas	0.0	0.0	0.0	0.0
Total	**3.1**	**30.0**	**36.5**	**37.7**

The dominant biomass cases involves 53% more biofuels of different types compared to the "Renew" battery success case and almost twice compared to the battery success case in 2050. Biokerosene as blended in jet fuels is almost equally developed in the three cases. The difference between the additional quantities in the dominant biomass case concerns the biodiesel, the methane from biogas and DME which develop substantially beyond 2030. According to the case developed using the biomass supply model of PRIMES the transformation processes producing biofuels shift towards 2nd generation biofuels, based on ligno-cellulosic plants allowing for reduced emissions in the biofuel production chain.

The dominant biomass case projects consumption of 112 Mtoe of biofuels by 2050, which represents roughly between 8 and 10% of gross inland consumption of the EU in 2050 in the context of the reference scenario. The results of the biomass supply model indicate that such a level of biofuel production implies almost exhaustion of land possibilities in the EU, according to strict criteria about sustainable land use and no interference with other land uses for food and forestry; the scenario also implies significant increase in biofuel and feedstock imports. The battery success case projects about 61 Mtoe of biofuels demand by 2050 which is certainly in the range of possibilities of the biomass industry in the EU. The "Renew" battery success case projects 73 Mtoe of biofuel demand by 2050 which is 35% less than in the dominant biomass case and can be considered as quite feasible being within the range of the future possibilities of the biomass industries of the EU.

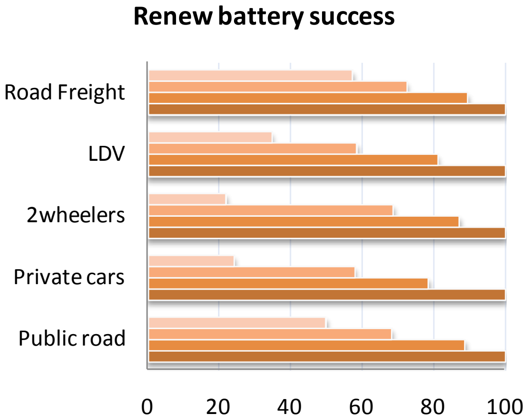
For private road vehicles, all cases have strong efficiency gains. In the battery success and "Renew" battery success cases the efficiency improvement is driven by the diffusion of mainly battery equipped electric cars and at a lesser extent of fuel cell cars.

The biomass dominant case has the least overall efficiency gains because it continues to rely on ICEs, which however by assumption improve in terms of specific energy consumption over time a trend which is significantly stronger than the other two cases. The battery success case sees the highest efficiency gains due to electrification; electric engines are more efficient than ICEs, even when these are improved.

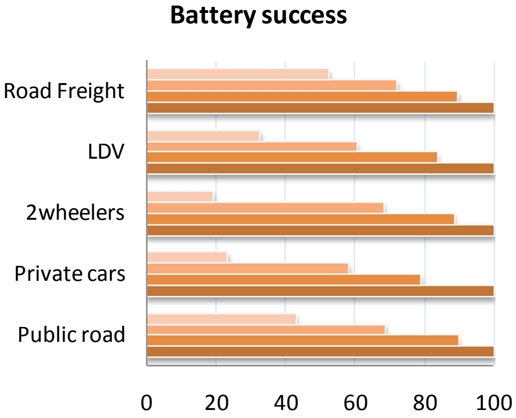
The effective specific consumption of an ICE in 2050, in the dominant biomass case which foresees the greatest improvements in this technology, reduces by 45% for conventional gasoline engines and by 50% for diesel engines compared to 2005; a battery electric vehicle in the battery success case in 2050 consumes about a fourth of a conventional ICE.

The evolution of the stock also reflects the tendencies described above for the different scenario cases. In the long-term in the dominant biomass case, the share of plug-in hybrids dominates because they allow for high efficiency while using biofuels combined with electricity. This contrasts the other two cases where the plug-in hybrids play a complementary role in the mid and the long-term in road transportation before high diffusion of mainly battery electric cars complemented by fuel cells cars.

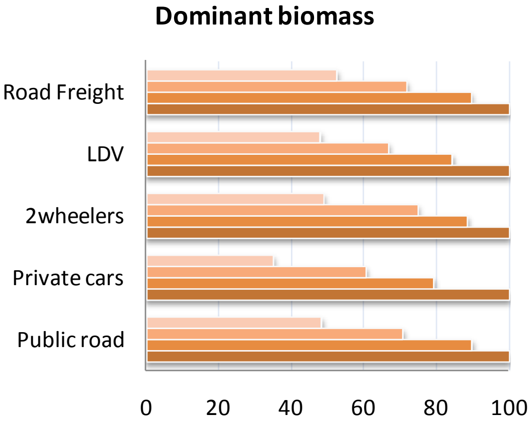
Figure 21: Specific Energy Consumption Index (2005=100)


Renew battery success

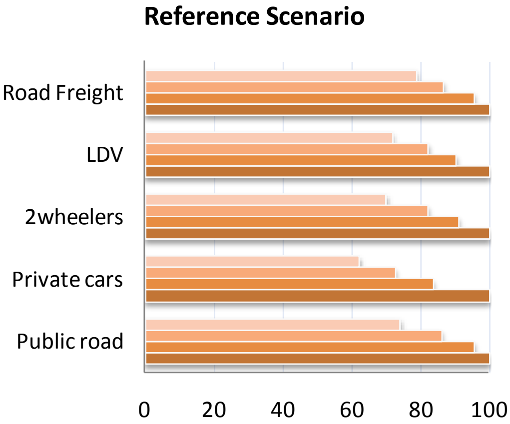
	Public road	Private cars	2wheelers	LDV	Road Freight
■ 2050	50.0	24.2	22.0	34.7	57.3
■ 2030	68.2	57.9	68.7	58.6	72.5
■ 2020	88.7	78.6	87.2	81.1	89.4
■ 2005	100	100	100	100	100


Battery success

	Public road	Private cars	2wheelers	LDV	Road Freight
■ 2050	43.0	23.4	19.1	32.7	52.5
■ 2030	68.7	58.2	68.2	60.5	72.1
■ 2020	89.6	78.9	88.5	83.6	89.6
■ 2005	100	100	100	100	100


Dominant biomass

	Public road	Private cars	2wheelers	LDV	Road Freight
■ 2050	48.4	35.1	48.9	48.1	52.6
■ 2030	70.8	60.6	74.9	66.8	71.9
■ 2020	89.8	79.2	88.6	84.4	89.6
■ 2005	100	100	100	100	100


Reference Scenario

	Public road	Private cars	2wheelers	LDV	Road Freight
■ 2050	74.1	62.3	70.1	71.8	78.7
■ 2030	86.1	72.7	82.2	82.3	86.6
■ 2020	95.5	83.6	91.0	90.3	95.5
■ 2005	100	100	100	100	100

Table 68: Stock of Private Cars and LDV

	Renew battery success			
(million vehicles)	2005	2020	2030	2050
Diesel Conventional	87.6	85.4	42.1	5.9
Gasoline Conventional	150.4	127.5	67.4	6.8
Hybrid	0.0	27.0	65.9	23.3
LPG and CNG	5.6	22.5	34.7	15.0
Ethanol car	0.0	0.1	1.1	1.1
Plug-in Hybrid	0.0	18.5	53.2	90.8
BEVs	0.0	2.5	27.8	149.3
FCEVs	0.0	0.5	3.4	32.5
Total	**243.6**	**284.1**	**295.5**	**324.6**

	Battery success			
(million vehicles)	2005	2020	2030	2050
Diesel Conventional	87.6	86.0	44.8	5.7
Gasoline Conventional	150.4	128.5	71.8	6.4
Hybrid	0.0	28.3	66.6	22.4
LPG and CNG	5.6	22.0	32.1	11.8
Ethanol car	0.0	0.1	0.7	0.7
Plug-in Hybrid	0.0	19.4	52.3	84.9
BEVs	0.0	0.2	25.4	156.9
FCEVs	0.0	0.0	2.5	37.3
Total	**243.6**	**284.5**	**296.1**	**326.2**

	Dominant Biomass			
(million vehicles)	2005	2020	2030	2050
Diesel Conventional	87.6	86.6	48.0	16.0
Gasoline Conventional	150.4	129.5	80.6	23.2
Hybrid	0.0	29.8	74.4	52.1
LPG and CNG	5.6	22.0	35.2	36.5
Ethanol car	0.0	0.1	2.2	5.8
Plug-in Hybrid	0.0	16.2	44.3	118.1
BEVs	0.0	0.1	9.2	51.6
FCEVs	0.0	0.0	1.2	12.1
Total	**243.6**	**284.4**	**295.0**	**315.5**

	Reference			
(million vehicles)	2005	2020	2030	2050
Diesel Conventional	87.6	115.6	114.9	105.2
Gasoline Conventional	150.4	156.0	160.4	152.4
Hybrid	0.0	5.7	27.0	71.4
LPG and CNG	5.6	13.8	13.7	14.7
Ethanol car	0.0	0.1	0.2	0.5
Plug-in Hybrid	0.0	0.0	0.1	0.1
BEVs	0.0	0.0	0.0	0.0
FCEVs	0.0	0.0	0.0	0.0
Total	**243.6**	**291.2**	**316.3**	**344.2**

Table 69: Stock of Trucks, Buses and Coaches

	Renew battery success			
(million vehicles)	2005	2020	2030	2050
Diesel Conventional	8.6	10.1	7.0	4.4
Hybrid	0.0	0.4	4.0	5.6
LPG and CNG	0.0	0.1	0.4	1.3
Electric	0.0	0.0	0.2	1.0
Fuel Cell	0.0	0.0	0.0	0.2
Total	**8.6**	**10.6**	**11.6**	**12.6**

	Battery success			
(million vehicles)	2005	2020	2030	2050
Diesel Conventional	8.6	10.1	7.0	4.0
Hybrid	0.0	0.4	3.9	5.0
LPG and CNG	0.0	0.1	0.4	1.0
Electric	0.0	0.0	0.3	2.4
Fuel Cell	0.0	0.0	0.0	0.4
Total	**8.6**	**10.6**	**11.6**	**12.7**

	Dominant Biomass			
(million vehicles)	2005	2020	2030	2050
Diesel Conventional	8.6	10.1	7.2	4.8
Hybrid	0.0	0.4	4.0	6.1
LPG and CNG	0.0	0.1	0.3	0.9
Electric	0.0	0.0	0.1	0.7
Fuel Cell	0.0	0.0	0.0	0.2
Total	**8.6**	**10.6**	**11.7**	**12.8**

	Reference			
(million vehicles)	2005	2020	2030	2050
Diesel Conventional	8.6	10.9	12.0	13.3
Hybrid	0.0	0.1	0.2	0.4
LPG and CNG	0.0	0.0	0.0	0.0
Electric	0.0	0.0	0.0	0.0
Fuel Cell	0.0	0.0	0.0	0.0
Total	**8.6**	**11.0**	**12.1**	**13.7**

The range limitations is found according to the modelling results to constitute an important constraint in certain market segments including long distance travelling by cars, freight transportation and inter-urban public transportation like coaches. Despite the improvement in range capability of batteries assumed in the battery success case the model projections show a small share of electric vehicles in trucks and coaches. For buses, coaches and trucks up to 2030 the stock is composed mainly of conventional vehicles and hybrids. The significant use of biofuels in particular, as well as LPG and methane, allows for emission reduction in these transport modes. In 2030 about 3.5% of trucks, buses and coaches are fuelled by methane and LPG. In the dominant biomass case this share further increases to 7% in 2050 and the remaining part of the stock is composed of conventional and hybrid technologies. In the battery success case a significant market share is gained by electric vehicles, especially by 2050. In 2050 electric vehicles represent 18.7% of total stock; this includes urban buses where the share of electric vehicles is 72% of total stock. In the "Renew" battery success case electric vehicles (for buses, coaches and trucks) gain a market share of 8% in 2050, while LPG and methane both obtain a share of 11%.

11.2 Effects of additional electricity and hydrogen demand on the overall electricity demand in PRIMES

In all the scenarios analysed within this study the model projects a strong increase in electricity consumption in the transport sector due to the at least partial electrification of road transport. As discussed above the highest increase in electricity demand is in the dominant electricity scenarios with battery success. The additional electricity required by the transport sector, additional to the stationary uses[57], in the battery success case is 421TWh in 2050 or an additional 14.3% above other uses of electricity.

Table 70: Final energy demand for electricity in a PRIMES decarbonisation scenario and the transport electricity demand from the transport scenarios

(TWh)	2005	2030	2050
Electricity demand in stationary uses	2688	3181	2944
Final electricity demand in transport			
Dominant electricity battery success	74	187	421
incremental electricity demand(*)		*5.9%*	*14.3%*
Dominant biomass		149	272
incremental electricity demand(*)		*5%*	*9%*
Renew battery success		184	376
incremental electricity demand(*)		*6%*	*13%*

(*) above other uses (stationary) of electricity

It is assumed within the overall PRIMES model that the charging of batteries will take place mainly during base load hours, as a result of development of smart metering and the

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[57] Stationary uses includes final energy demand of electricity from industry, households and the tertiary sector

application of price-based incentives with electricity tariffs varying by time of use. In this way the charging of batteries will have a load profile which will exert a positive effect on power generation by smoothing the overall load curve; the smooth load curve is beneficial for the cost of electricity and for the development of capital intensive power plant technologies, as those that enable decarbonisation in the power sector (RES, CCS and nuclear), since it allows for better use of large base load devices and reduces the necessity for peak devices.

These power system changes have been simulated using the PRIMES model and has been reflected onto the projection of electricity prices to the future, which apply to demand sectors, including transportation.

In the fuel cell success scenario where both battery based vehicles as well as fuel cell vehicles develop, the demand for electricity increases more than in the battery success scenarios, because hydrogen is produced by electrolysis in order to benefit from decarbonised electricity in the context of the emission reduction scenarios. Hydrogen production is simulated using the PRIMES model which determines the additional electricity demand for that purpose and the selling prices of hydrogen (per sector) which allow for recovering of total costs, including capital costs. Hydrogen production also helps maintaining high levels of generation from intermittent renewables as it provide an indirect storage for these sources. Such effects were modelled through the PRIMES model.

Whereas in 2050 the direct electricity demand for the transport sector is still higher than the demand for the electricity for hydrogen production, by 2050, in the fuel cell cases the electricity demand for hydrogen production is higher than the direct demand for electricity adding to total electricity demand above electricity amounts for stationary uses.

Table 71: Electricity demand from the transport sector including indirect demand for hydrogen production

	2030			2050		
(TWh)	Electricity demand for hydrogen production	Direct electricity demand from grid[58]	Total electricity demand	Electricity demand for hydrogen production	Direct electricity demand from grid[59]	Total electricity demand
Reference	0	99	99	0	103	103
Fuel cell success	134	176	311	415	328	742
Dominant Biomass	5	149	154	53	272	326
Renew fuel cell success	99	173	271	353	298	651

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[58] Direct electricity demand from grid includes the electricity for BEVs and PHEVs of all kinds and of rail

[59] Direct electricity demand from grid includes the electricity for BEVs and PHEVs of all kinds and of rail

The total additional demand for electricity in the scenarios with hydrogen, is therefore substantially higher than the battery cases: the dominant electricity with fuel cell success scenario has an overall electricity demand which is 76% higher than the dominant electricity battery success scenario. The increased demand for electricity from the transport sector including hydrogen production therefore corresponds to an incremental demand of 25.2% additional to the stationary uses. The possibility to produce hydrogen at all times leads to a more efficient use of base load power plants, which leads to further benefits from a cost perspective for the power sector which partly compensates for the additional costs of hydrogen production.

Table 72: Final energy demand for electricity in a PRIMES decarbonisation scenario and the transport electricity demand from the transport scenarios incl. electricity necessary for hydrogen production

(TWh)	2005	2030	2050
Final energy demand for electricity excl. transport	2688	3181	2944
Transport electricity demand (incl. indirect demand for hydrogen production)			
Dominant electricity fuel cell success	74	311	742
incremental electricity demand		*9.8%*	*25.2%*
Dominant biomass		154	326
incremental electricity demand		*5%*	*11%*
Renew fuel cell success		271	651
incremental electricity demand		*9%*	*22%*

Although the incremental demand of electricity for transport relative to stationary uses of electricity is substantial, the overall scenario analysis shows that this additional use of electricity can have beneficial impacts on the load curve for electricity, by increasing base load and therefore on the costs of electricity, by reducing the necessity of peak load devices and having a more extensive use of base load power plants.

11.3 Primary energy demand

Total primary energy consumption in the battery success case by 2050 is lower than in the "Renew" battery success and the dominant biomass case by 3.5% and 16.6% respectively (see Table 73); battery success case delivers the highest primary energy savings compared to the Reference scenario. In battery success case the diffusion of BEVs leads to significant efficiency gains and thus to lower demand for energy (i.e. electricity).

In all three cases substantial reduction in crude oil consumption is observed compared to current levels. In dominant biomass case the crude oil has been substituted with biomass feedstocks which are necessary for biofuels production. Vehicles running on biofuels in the dominant biomass case cannot compete in terms of efficiency with BEVs in battery success and "Renew" battery success case; this explains the fact that dominant biomass case delivers the highest primary energy consumption of all three cases.

The additional demand for natural gas in the emission reduction scenarios is substantial compared to the past but is small if compared to total natural gas consumption in the EU as projected by PRIMES in decarbonisation scenarios for 2050. That additional demand is of the order of 7% above total gas demand for other purposes. By 2030, this additional demand for natural gas also amounts to 7%.

Table 73: Primary energy consumption in the transport sector

	Renew battery success			
(Mtoe)	2005	2020	2030	2050
crude oil	371.3	334.9	264.5	105.1
natural gas	5.2	12.8	21.0	20.0
biomass	3.7	31.6	41.6	83.7
solids	5.1	18.8	12.0	9.9
other RES	0.8	2.7	6.4	17.8
Nuclear	5.6	7.0	13.5	28.4
Total	**391.7**	**407.7**	**358.9**	**264.8**

	Battery success			
(Mtoe)	2005	2020	2030	2050
crude oil	371.3	337.3	266.0	107.3
natural gas	5.2	12.3	20.3	17.8
biomass	3.7	31.5	41.8	73.0
solids	5.1	18.6	11.9	11.2
other RES	0.8	2.6	6.4	20.3
Nuclear	5.6	6.7	13.3	32.4
Total	**391.7**	**409.0**	**359.8**	**262.1**

	Dominant Biomass			
(Mtoe)	2005	2020	2030	2050
crude oil	371.3	338.2	268.2	102.5
natural gas	5.2	12.3	18.1	17.2
biomass	3.7	31.8	49.6	119.2
solids	5.1	18.5	11.3	6.7
other RES	0.8	2.5	5.0	11.7
Nuclear	5.6	6.5	10.6	18.4
Total	**391.7**	**409.8**	**362.7**	**275.6**

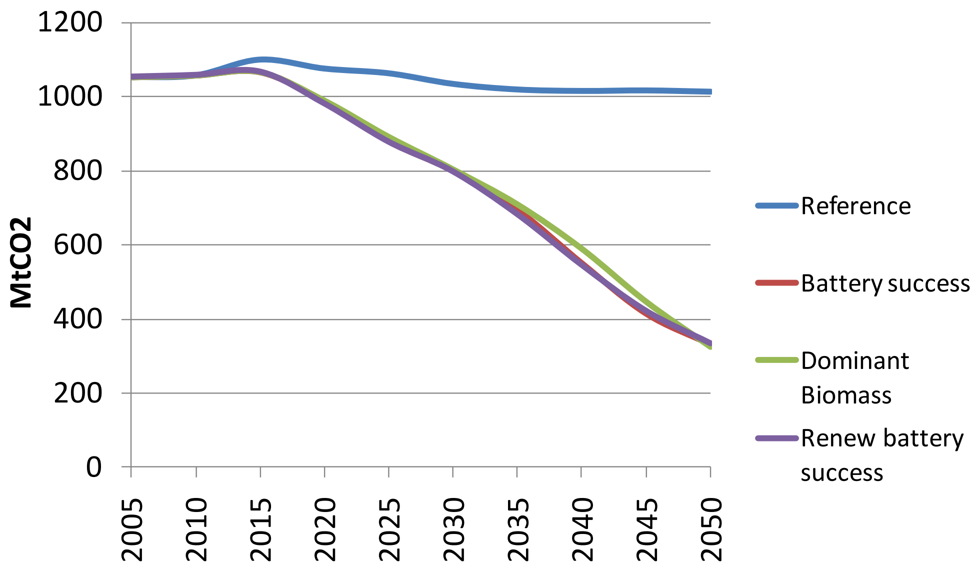
	Reference			
(Mtoe)	2005	2020	2030	2050
crude oil	371.3	375.2	354.5	337.7
natural gas	5.2	9.3	14.0	19.1
biomass	3.7	32.0	39.0	41.0
solids	5.1	24.5	17.1	6.3
other RES	0.8	2.1	2.9	3.0
Nuclear	5.6	4.9	5.6	5.8
Total	**391.7**	**448.1**	**433.0**	**412.9**

11.4 Direct and indirect CO_2 emissions

All scenarios analysed within this study achieve just below 70% emission reductions compared to 2005 which is equivalent to approx. 60% emission reductions from 1990 levels. All scenario cases achieve the target of CO2 emission reduction set by the White Paper; other objectives adopted by the White Paper such as limitation of growth of congestion were not met as they were not within the context of the current study.

The CO_2 emission reduction profiles of the Reference, the battery success, the Dominant biomass and the Renew battery success cases with CO_2 standards are shown in **Error! Reference source not found.**. The battery success and Renew battery success cases follow a similar reduction of CO_2 emissions across the projection period. The emissions reduction profile of the dominant biomass case slightly deviates between 2030 and 2045 before reaching the 60% emission reduction target in 2050.

Figure 22: Direct CO_2 emissions in the transport sector



In all cases road transport emissions decrease more significantly than non-road transport emissions. In non-road transport emissions do not decrease as substantially mainly due to the increased activity in aviation. The lower energy prices assumed in the decarbonisation context lead to this increase; in terms of emissions this leads to slightly higher emissions than in the Reference scenario. Emissions do not increase as steeply due to the slightly higher energy efficiency and the slow penetration of bio-kerosene. By 2050 due to large scale penetration of bio-kerosene the emissions for aviation also decrease. Rail emissions decrease substantially in all scenarios including the Reference scenario due to the wide-scale electrification of the sector. Emissions in inland navigation reduce mainly due to the introduction of biofuels, and therefore reduce most in the dominant biomass case.

Large scale emissions reductions are achieved in all road transport scenarios. Private passenger road transport is responsible for the majority of the CO2 emission reductions in all scenarios; in the dominant electricity with battery success case private road transport reduces 68% of emissions, whereas in the dominant biomass case, where it represents the least emission reduction it still represent 62% of emission reductions. Private road transport already reduced emissions in the Reference scenario and is projected under the scenarios to achieve enormous emissions reductions of up to 87% in the dominant electricity with battery success. The changes in emissions in the dominant electricity and the “Renew” scenarios, are due to the enormous shift towards zero tailpipe emission vehicles. Road freight transport which increased emissions in the Reference scenario sees a decline in emissions in all the scenarios. The share of overall emission reductions achieved by freight road transport ranges between 24% in the dominant electricity and “Renew” scenarios, and 29% in the dominant biomass scenarios in which the higher use of biofuels and the higher energy efficiency lead to higher emission reductions. Emissions from public road transport are very limited in the overall, representing between 1 and 2% of total transport emissions. Nonetheless public road transport achieves between 68% in the dominant electricity scenarios and 77% in the dominant biofuel scenarios in which as for freight transport the higher shares of biofuels and of the increased energy efficiency play a larger role.

Table 74: CO$_2$ emissions by transport mode

		Reference scenario				Battery success			
	2005 MtCO$_2$	2030		2050		2030		2050	
		MtCO$_2$	% diff. from 2005	MtCO$_2$	% diff. from 2005	MtCO$_2$	% diff. from 2005	MtCO$_2$	% diff. from 2005
Private road	570	485	-15%	451	-21%	339	-41%	77	-87%
Road freight	294	315	7%	321	9%	227	-23%	118	-60%
Public road	15	14	-7%	13	-15%	10	-31%	5	-68%
Rail	9	3	-66%	1	-94%	3	-65%	0	-95%
Aviation	147	198	35%	209	42%	201	36%	116	-21%
Inland navigation	17	20	20%	21	26%	20	19%	16	-6%
Total emissions	**1053**	**1036**	**-2%**	**1015**	**-4%**	**800**	**-24%**	**332**	**-68%**

	Dominant biomass				Renew battery success			
	2030		2050		2030		2050	
	MtCO$_2$	% diff. from 2005	MtCO$_2$	% diff. from 2005	MtCO$_2$	% diff. from 2005	MtCO$_2$	% diff. from 2005
Private road	344	-40%	123	-79%	332	-42%	82	-86%
Road freight	227	-23%	85	-71%	232	-21%	121	-59%
Public road	11	-31%	4	-77%	10	-31%	5	-69%
Rail	3	-66%	0	-96%	3	-66%	0	-96%
Aviation	200	36%	104	-29%	201	36%	112	-24%
Inland navigation	20	18%	10	-41%	20	18%	14	-18%
Total emissions	**805**	**-24%**	**326**	**-69%**	**797**	**-24%**	**334**	**-68%**

Table 75 shows the WTW emissions for the scenarios and incremental emissions compared to the TTW emissions. It shows that WTW emissions are only limitedly larger then TTW emissions in the long term. In the long term the decarbonisation of the energy system allows for limited additional CO2 emissions from the WTT process. These emissions are linked to the energy consumption during the production of fuels and mostly to the production of biofuels.[60] As can be observed in Table 75 the amount of WTT emissions decrease over time as the overall energy system also decarbonises, were this not the case overall emissions would be very different.

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[60] It is reminded that emissions due to land-use, land-use change an indirect land use change

Table 75: WTW CO_2 Emissions in the transport sector

	2005		2030		2050	
	WTW CO_2 emissions in $MtCO_2$	% additional to TTW	WTW CO_2 emissions in $MtCO_2$	% additional to TTW	WTW CO_2 emissions in $MtCO_2$	% additional to TTW
Reference	1157	9.9%	1151	11.1%	1093	7.7%
Battery success			884	10.5%	351	5.7%
Dominant Biomass			886	10.1%	355	9.0%
Renew battery success			880	10.4%	354	6.1%

11.5 Average yearly investment requirements and fuel expenses

Yearly average investment requirements increase significantly in the Reference scenario: for households from about € 400 billion to more than € 500 billion by 2050 and for business from about € 200 billion to more than € 300 billion by 2050. These investments include the entire expenditures related to the fleet but exclude the basic transport infrastructure like rail lines, harbours, airports, roads, etc. The expenditures for investment have been annualised. Thus, Table 76 shows the average annual cash flow payments.

In emission reduction scenarios, the change in average annual investment requirements is substantial relative to the Reference. However, the results show that the highest percentage change of expenditures for purchase of transport equipment takes place in the long term (after 2030), which is the period of full deployment of the new fuel technologies.

The yearly average expenditures for investment in the first decade of the projection period are similar between the scenarios because the available options are almost the same for all scenarios. The main differences become apparent in the last 20 years of the projection period when a variety of options become available and cause a differentiation of the costs.

The investment requirements are lowest in the fuel cell success scenarios due to the assumed low capital costs for the fuel cell vehicles. The investment requirements are highest in the renew cases because of the assumption of the development of all options simultaneously which does not allow the single options to reach their full cost reduction potential.

Table 76: Average annual investments and fuel expenses by households and business

	Reference scenario				
	2011-2020	2021-2030	2031-2040	2041-2050	2011-2050
Transport expenditures by household					
Purchase of equipment	413	461	496	517	472
Fuel expenses	283	344	368	394	347
Transport expenditures by business					
Purchase of equipment	218	256	277	309	265
Fuel expenses	190	248	277	307	256

	Battery success					**Fuel cell success**				
	2011-2020	2021-2030	2031-2040	2041-2050	2011-2050	2011-2020	2021-2030	2031-2040	2041-2050	2011-2050
Recharging infrastructure	*72*	*147*	*132*	*110*	*461*	*71*	*127*	*88*	*80*	*366*
Transport expenditures by household						Transport expenditures by household				
Purchase of equipment	424	529	611	661	556	426	532	617	664	559
Fuel expenses	287	279	230	197	248	287	278	224	198	247
Transport expenditures by business						Transport expenditures by business				
Purchase of equipment	220	275	306	349	287	220	275	305	342	285
Fuel expenses	200	224	211	211	212	223	217	211	115	191

	Dominant biomass					**Renew battery success**				
	2011-2020	2021-2030	2031-2040	2041-2050	2011-2050	2011-2020	2021-2030	2031-2040	2041-2050	2011-2050
Recharging infrastructure	*61*	*92*	*63*	*64*	*280*	*80*	*144*	*126*	*82*	*432*
Transport expenditures by household						Transport expenditures by household				
Purchase of equipment	424	26	584	638	543	426	532	617	664	559
Fuel expenses	288	285	258	245	269	287	278	224	198	247
Transport expenditures by business						Transport expenditures by business				
Purchase of equipment	220	274	302	339	284	220	275	305	342	285
Fuel expenses	201	226	217	226	217	200	224	212	221	214

Table 77: Percentage change of average annual transport expenditures from Reference scenario

	Battery success					Fuel cell success				
	2011-2020	2021-2030	2031-2040	2041-2050	2011-2050	2011-2020	2021-2030	2031-2040	2041-2050	2011-2050
	Transport expenditures by household					Transport expenditures by household				
Purchase of equipment	3%	15%	23%	28%	18%	3%	17%	19%	22%	16%
Fuel costs	2%	-19%	-37%	-50%	-28%	2%	-19%	-33%	-41%	-25%
	Transport expenditures by business					Transport expenditures by business				
Purchase of equipment	1%	7%	10%	13%	8%	1%	8%	10%	11%	8%
Fuel costs	6%	-10%	-24%	-31%	-17%	6%	-10%	-23%	-29%	-16%
	Dominant biomass					Renew battery success				
	2011-2020	2021-2030	2031-2040	2041-2050	2011-2050	2011-2020	2021-2030	2031-2040	2041-2050	2011-2050
	Transport expenditures by household					Transport expenditures by household				
Purchase of equipment	3%	14%	18%	23%	15%	3%	15%	24%	28%	19%
Fuel costs	2%	-17%	-30%	-38%	-22%	1%	-19%	-39%	-50%	-29%
	Transport expenditures by business					Transport expenditures by business				
Purchase of equipment	1%	7%	9%	9%	7%	1%	7%	10%	10%	8%
Fuel costs	6%	-9%	-22%	-26%	-15%	5%	-10%	-23%	-28%	-16%

By 2050, fuel expenses decline in all emissions reduction scenarios. We remind that the emission reduction scenarios were conceived in the context of a global emissions reduction effort, as simulated for the "Roadmap for moving to a competitive low carbon economy in 2050"[61]. In this context world fossil fuel prices are projected to decrease in the future from their levels in the Reference scenario. The results shows that fuel costs in transport decrease in the emission reduction cases firstly because of the use of more efficient technology/fuel and secondly because fossil fuel prices increase less than in the Reference scenario. The contribution of the fossil fuel price reduction in total fuel payments decreases in the long-term as use of oil products declines substantially. In the emission reduction scenarios however capital costs increase considerably. According to model results the net effect of the emissions reduction effort on total transportation costs remains positive, which means that the additional capital cost dominates over reduced fuel costs.

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[61] COM (2011) 112.

Table 78: Expenditures for fuel imports excl. biomass

	2005	Reference		Battery success	
		2030	2050	2030	2050
Bln. EUR'08	124.9	238.4	298.5	138.2	55.8
Diff. to 2005		91%	139%	11%	-55%
		Dominant biomass		Renew battery success	
		2030	2050	2030	2050
Bln. EUR'08		138.4	53.4	137.7	55.5
Diff. to 2005		11%	-57%	10%	-56%

Table 78 shows that the external fuel bill of the EU is greatly reduced as a result of the emission reduction effort. Even if world energy prices were not reduced, the external bill of the EU would be in 2050 one third of its value in the reference scenario; it would be half by 2030 already.

The infrastructure costs for fuels distributed in filling stations are assumed to be recovered by fuel prices and so the consumers will not bear additional costs for infrastructure as is currently the case with conventional fuels. The cost of electric infrastructure has been calculated separately as it is not the amount of electricity consumed which determines the necessity for the infrastructure but the amount of vehicles. The electricity prices in the context of emission reduction scenarios include the additional cost for charging infrastructure which is assumed to be socialised, in the sense that all electricity consumers and not only the infrastructure users pay for the infrastructure costs. The costs calculated are highest in the battery success cases – renew or dominant electricity- where the amount of electric vehicles is highest; the additional costs for infrastructure also include the necessary grid investments.

The investment required for developing the necessary recharging infrastructure is estimated at 211 billion € in the battery success case and at 207 billion € in the Renew battery success case[62].

It has been assumed that a slow recharging point is available for each vehicle, as well as a limited amount of fast charging points for the overall vehicle park. For trucks and coaches large recharging stations are assumed to be developed, whereas for urban buses swapping stations are assumed to be set up. Reinforcement of the low and medium voltage power grid is also taken into account in cost calculations. To recover this grid investment an additional levy of 1.7EUR/MWh should be raised, if the recovery of cost of recharging infrastructure is fully socialised (which means that all consumers pay for that levy). If instead only vehicles owner pay for this infrastructure then the corresponding levy would be in the order of 15EUR/MWh. The issue of financing, investment management and tariff regulation deserve further study as many possibilities exist with different implications on the pace of infrastructure development and its cost.

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[62] The present value of the electric road infrastructure costs is derived using a discount rate of 4%.

In terms of average total cost of transportation, the model-based projections show that in the reference scenario the unit total cost of passenger transportation remains rather stable over time, despite the increase in fuel prices as projected in this scenario. The increasing fuel prices are compensated by the projected progress in energy efficiency of ICE cars. In the emission reduction scenarios, unit fuel costs (per unit of passenger activity) reduce mainly as a result of great energy efficiency gains, but the unit cost of capital increases. A similar trend is observed for freight transport, for which however unit total cost of transportation increases faster than for passenger transport, as the freight sector has limited possibilities for shifting to new energy carriers. The increasing production of biofuels, as required in the emission reduction scenarios, imply higher biofuels prices in the future, as shown by the PRIMES biomass model results, due to increasing costs of additional land and feedstock processing resources that will be required and despite technology progress and productivity gains in the biomass supply sector. So biofuels penetration induce higher unit costs of transport in the sectors that in the future are depending on this energy form. The general shift in the structure of transport costs towards more capital costs and less variable costs raises concerns about the affordability for a class of consumers (low income classes and small and medium enterprises). The affordability issue arises because this class of consumers have lower cash flow possibilities and have more difficult access to bank borrowing; thus there is a risk of being deprived from having plenty access to the new vehicle and transport technologies within the emission reduction prospect. There could be also concerns about the marketability of the more expensive vehicles in the future; methods of transforming ad hoc payments for batteries into periodical payments, as it has been already proposed, may help improving marketability.

The structure of expenditures is changing in the emission reduction scenarios, with considerably higher average annual expenditures for purchasing transport equipment over the projection period being compensated to a certain extent by lower fuel costs. The cash flow requirements for car purchasing by households increase substantially more than for business as the electrification deploys at much larger extent in private road transport rather than in public and freight transport.

12 Uncertainties and sensitivity analysis on battery and fuel cell related costs

The dominant electricity context, in which battery and fuel cell successes were assessed, depends on optimistic technological progress which is assumed to deliver high reductions in battery and fuel cell costs. It is assumed that if sufficient technological progress takes place the infrastructure will develop accordingly. The main uncertainty of dominant electricity is therefore what will happen if industry fails to deliver the aforementioned progress.

The aim of the dominant biomass context is to assess the role of biofuels in the transport sector without relying on ambitious technological progress such as battery and fuel cell cost reduction; it depends though on the delivery of expected results on technological options that are crucial for enhancing biofuels supply and its prospects in the EU transport sector.

The "Renew" context assumes that all necessary refuelling and recharging infrastructure will be provided at least in the short to mid-term. All alternative fuels have the chance to compete with each other and gain higher shares in the transport fuel mix and in specific transport modes. The "Renew" cases depend on several alternative fuels and are the ones with the lowest uncertainty; higher costs are implied though as multiple infrastructures are developed.

In the following a sensitivity analysis is presented regarding the assumptions adopted for the Dominant Electricity context concerning battery and fuel cell costs.

12.1 Sensitivity analysis on battery costs reduction – 3 different cases

Due to the high interest in battery electro-mobility a large number of literature sources are available about the possible development of battery costs in the future. A summary of projections can be found in Table 79 (both in dollars and in Euros[63]).

Table 79: Battery costs in literature

Source	Assumptions/Vehicle Type	Cost [$/kWh]	Cost [€/kWh]
Kahlhammer et al. 2007	PHEV 10, with 100000 units produced	395	321
	PHEV 40, with 100000 units produced	260	211
US DOE	Goal by 2015	250	203
USABC targets	PHEV 10	300	244
	PHEV 40	200	163

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[63] An exchange rate of 1€ = 1.23$ was assumed.

Source	Assumptions/Vehicle Type	Cost [$/kWh]	Cost [€/kWh]
BLUEPRINT FOR A SECURE ENERGY FUTURE (U.S.)	Recovery Act ($2.4 billion for battery and R&D). Target: capacity to produce 40% of the world's advanced batteries (2015); 330$/kWh in 2015 and 110$/kWh in 2030	330 (2015) 110 (2030)	268 89
EUROBAT (2005)	Recent price 2005	1000-2200	813-1789
	2020; 296$/kWh target at end of 15 year research programme; 100k production volume/annum; 30kWh battery	296	241
Challenge Bibendum Battery Round Table (2007)	Recent price2007	1000-2000	813-1626
ANL (2000)	Future; Optimistic projection based on future price of materials	250	203
EPRI (2005)	Future; 100k production volume/annum; 30kWh Battery	280	228
CARB (2007)	Future; 100k production volume/annum; 25kWh Battery	240-280	195-228
USABC target Selling Price - 25,000 units @ 40 kWh($/kWh), from (USABC n.d.)	EV (Minimum Goals for Long-Term Commercialization)	150	122
	EV (Long-Term Goal)	100	81
IEA PHEV and EV Roadmap from (IEA, Technology Roadmap: Electric and plug-in hybrid electric vehicles 2009)	expected near-term, high-volume battery prices	500	407
(McKinsey 2009)	Range for 2008, based on industry reports (505-1143 EUR/kWh)	681-1542	554-1254
A portfolio of power-trains for Europe, from (McKinsey 2010)	Battery costs in 2020 are based on data submitted by participating car manufacturers and suppliers	283-554	230-450
Techno-economic analysis of low-GHG emission passenger cars (Safarianova 2011)	250€/kWh by 2020	308	250
Techno-economic and behavioural analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system in the UK (Offer, et al. 2011)	200-300$/kWh by 2030	200--300	160-244

Industry comments			
Nissan Leaf[64]	Expected replacement costs 10000$, battery pack 24kWh	417	339
Martin Eberhard[65]	Approx. 2020	200	163

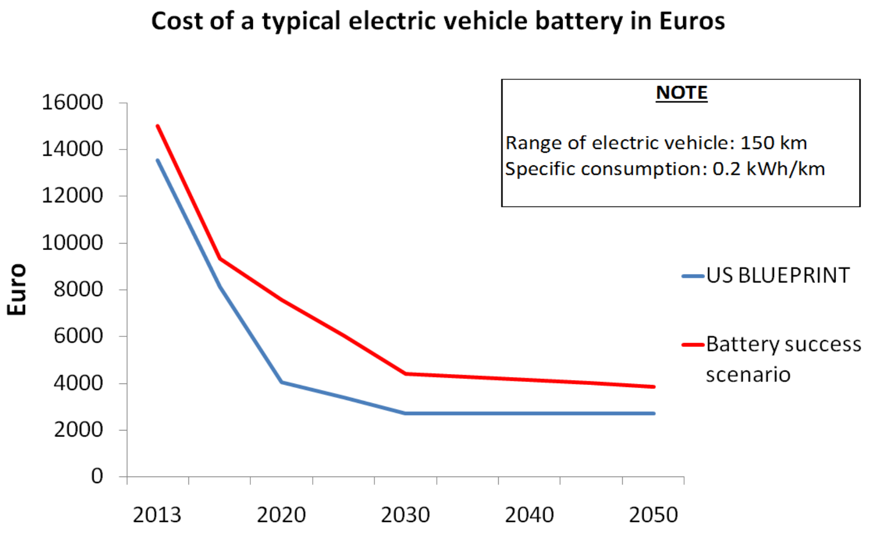
The estimates in the literature present a high degree of discrepancy concerning future costs of electric vehicles.

Current battery price estimates range from 417$/kWh for the Nissan Leaf to an industry report of McKinsey of 2008 where battery costs are estimated at a maximum of 1542$/kWh. For the period of time beyond 2020 the projections range from 100$/kWh of the USABC to the less optimistic estimates of 300 to 700$/kWh depending on the type of vehicle considered. For the years up to 2015 the costs assumed in PRIMES-TREMOVE are in line with most projections including the IEA estimate of near-term prices of 500$/kWh.

The battery success case assumes that the cheapest battery will cost 141 EUR/kWh by 2050 this being within the spectrum of the literature.

A recent study published in March 2011 by US government makes a forecast on the evolution of the cost of a typical electric vehicle battery up to 2030 (see Figure 23 which shows the projection assumed in this study). The comparison indicates very similar learning curve for battery costs and the discrepancies are rather small.

Figure 23: Comparison of assumed costs of a typical electric vehicle with battery between US BLUEPRINT and PRIMES-TREMOVE



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[64] http://www.autoblog.com/2009/08/01/2010-nissan-leaf-electric-car-in-person-in-depth-and-u-s-b/ (last accessed 21st October 2010)

[65] Co-founder of Tesla, since early 2009 electric vehicle engineering director at Volkswagen's Electronics Research Laboratory (ERL) in Palo Alto, California. http://electric-vehicles-cars-bikes.blogspot.com/2010/08/eberhard-500-mile-evs-by-2020.html

A sensitivity analysis regarding the impact of battery cost reduction on the projected stock of BEVs has been carried out. Three cases were quantified as regards the battery costs evolution within the context of the battery success case. The most optimistic case represents the battery success case as presented in section 7.2. Table 80 summarises the cost of batteries and the related volume of BEVs operating in the market by 2050.

Table 80: Stock of battery electric cars and LDVs by 2050 in three different battery cost reduction cases

	Battery success	Battery success variant 1	Battery success variant 2
Battery cost in 2050 (€/kWh)	141	170	210
stock of battery electric cars and LDVs (in million vehicles)	157	131	100

In the most optimistic case (battery success case) with battery costs reaching 141 Euro per kWh by 2050, the EU-27 stock of battery electric cars and LDVs represents roughly 48% of the total stock. Assuming that the battery costs do not reduce below 170 Euro per kWh by 2050, the stock of BEVs reduces to 40% of the total stock. In the less optimistic case with the battery costs assumed at 210 Euro per kWh by 2050, the stock of battery electric cars and LDVs further reduces to 30% of total stock. So, the results are sensitive on assumptions about future battery costs.

12.2 Sensitivity analysis on fuel cell stack and system costs reduction – 3 different cases

For the fuel cell success case it is assumed that fuel cell costs decrease drastically as suggested by a recent study of McKinsey. The reduction takes place already by 2020 and beyond that data further decreases lead fuel cell costs to a level as low as 25 €/kW in 2050.

The uncertainties surrounding future evolution of fuel cells costs are higher than for batteries. There have been numerous studies about FCEVs but most of which date back to the period 2000-2005. The recent study on fuel cell technology prospects carried out by McKinsey in 2010 proposes a learning curve for fuel cell stack and system costs which exhibit high cost reductions driven by engineering improvements, mass scale production and limited use of scarce materials like platinum. The projected fuel cell stack cost range between 42 and 252 €/kW in 2015 with a central value of 110 €/kW; for 2020 the fuel cell costs range between 16 and 98 €/kW with a central value of 43€/kW. (Safarianova 2011) in their report also mention that the fuel cell stack cost could decrease down to 60 €/kW already by 2015.

Table 81 summarises the projections about fuel cells as proposed by published studies.

Table 81: Fuel cell costs in literature

Source	Assumptions/Vehicle Type	Cost [$/kW]	Cost [€/kW]
Prospects for hydrogen and fuel cell, IEA (2005)	Fuel cell costs would decline over time to between 35$/kW (optimistic) to 75$/kW	35-75	28-61
(McKinsey 2010)	500€/kW in 2010 110€/kW (42-252 €/kW) in 2015; 100,000 FCEV units 43€/kW (16-98 €/kW) in 2020; 1,000,000 cumulative FCEV units 42% reduction in fuel cell costs in 2050 compared to 2020 levels Based on data submitted by participating car manufacturers and suppliers	135 (2015) 53 (2020)	110 (2015) 43 (2020)
Cascade mints (Techpol projections), 2007	24€/kW in 2050; Fuel cell stack costs in 2050 are target prices which take into account expected innovation combined with learning effect (standardised products)	30	24
ADL (2001)	Technical cost projections:181$/kW; 50,000 units per year	181	147
James(2002)	Technical cost projections: 44-150$/kW (depends on stack characteristics); 500,000 units per year	44-150	36-122
Tsuchiya(2004)	Cost projections: 38-145$/kW; by 2020 and 5000000 cumulative FCEVs sales	38-145	31-118
Techno-economic and behavioural analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system in the UK (Offer, et al. 2011)	35$/kW-75$/kW by 2030	35-75	28-61
Techno-economic analysis of low-GHG emission passenger cars (Safarianova 2011)	Capital cost of 60 €/kW in 2015	74	60

A sensitivity analysis has been carried out regarding fuel cell stack costs. Three cases were quantified with different learning potentials. The sensitivity analysis takes as basis the fuel cell success scenario case which was presented in section 7.3. The costs shown in Table 82 correspond to fuel cell stack costs and do not include the rest of the fuel cell system costs (periphery costs); the system costs assumed in the sensitivity analysis increase proportionally with the fuel cell stack costs and are of the same order of magnitude.

Table 82: Stock of fuel cell electric cars and LDVs by 2050 in three different battery cost reduction cases

	Fuel cell success	Fuel cell success variant 1	Fuel cell success variant 2
Fuel cell stack cost in 2050 (€/kW)	25	40	60
stock of fuel cell electric cars and LDVs by 2050 (in million vehicles)	128	101	79

The most optimistic case (fuel cell success case) which assumes that the fuel cell stack cost decreases to 25 Euro per kW by 2050, leads total stock of fuel cell passenger cars and LDVs to cover 39% of the total stock. When assuming that the fuel cell stack cost does not decrease below 40 Euro per kW by 2050, the share of FCEVs reaches in total stock decreases to 30%. The least optimistic case with fuel cell stack cost at 60 Euro per kW by 2050, further reduces the share to 24%. It is concluded that the fuel cell vehicle prospects also heavily depend on fuel cell costs.

13 Exploration of a synthetic fuel scenario

Synthetic fuels is a generic nomenclature which can refer to a wide range of fuels derived from a large variety of feedstocks via processes which control the molecular structure to an end product which can be gaseous or liquid. The control of the molecular structure of the end product can lead to the creation of fuels that are fully compatible with the current energy system, without the necessity for adaptation of the vehicle technology or for the construction of additional infrastructure.

The terminology synthetic fuels refers more often (and this will be the definition used in the following text) to coal-to-liquid (CtL), gas-to-liquid (GtL) and biomass-to-liquid (BtL), as well as synthetic methane and DME. The liquids produced through these processes which will be considered in the following are diesel-like fuels, gasoline-like fuels and jet fuels for aviation, DME and methane. In the perspective of having full compatibility with the current vehicle technologies the most important are the technologies which produce liquid fuels (XtL), substitutable with the current ones therefore diesel, gasoline and kerosene.

In the study until now DME and synthetic methane from biomass are considered but are assumed to remain complementary fuels in all scenarios. The synthetic fuels with large substitution potentials are those producing liquids. CtL technology produces liquid fuels (diesel, gasoline or jet fuel) from coal; this technology is economically viable in areas where there is high availability of coal at low cost. In a context of climate action on a global level, as was considered the background for this study, such a technology does not fit in the picture due to the high emissions related to this technology. Two further technologies remain GtL and BtL.

The model used for the current analysis does not distinguish between BtL and first generation biodiesel which may not fully compatible with the current vehicle technology; there is a distinction between biodiesel for blending (mainly 1st generation biofuel) which can only be blended up to a certain percentage and B100 which is diesel from 100% biomass origin. The B100 is assumed to enter the market from 2025 onwards and is considered to be a perfect substitute, therefore a BtL- diesel. In the previous scenarios the use of biofuels is considered to be BtL.

GtL is a process which, for economic reasons, can only occur in large scale production plants, therefore close to gas production where gas is cheap and abundant. For small quantities it is an option only in remote areas, where the transportation of the gas through other means is also expensive. When considering, as in the case for the scenario described below, large scale production of GtL, the scenario basis on the assumption of large scale availability of gas due to production of gas from shale and additional resources. As the Prometheus world energy model is confirming that a scenario with large scale use of GtL requires large scale production of gas from shale in particular in north America and the CIS states, in particular Russia; in this context the EU would be importing GtL as a transport fuel and using BtL as a complement similarly to the case in the dominant biomass case which achieves the 60% emissions reduction target.

The model based analysis projects a price of the imported GtL at similar levels to the price of liquid oil fuel (gasoline and diesel) in the context of a global action scenario, as is the context for all the scenario analysed within this study. The framework of global climate action leads to substantially lower international fuel prices compared to a Reference scenario, where the rest of the world continues to operate in an almost business as usual environment. In the context of this GtL sensitivity it is assumed that gas substitutes oil as a commodity and there is no development in transport of electric or fuel cell vehicles; due to this use of gas as a single fuel monopoly it is expected that the prices of GtL will not drop below the (low) prices for diesel and gasoline assumed in the decarbonisation context with global action.

13.1 World energy context as derived from the Prometheus world energy model

The scenario implemented using the PROMETHEUS world energy model aims at exploring the consequences of increased gas availability (increased non-conventional gas resources) which is assumed to be used also as an alternative transport fuel in the form of GTL, in the context of global action towards emission reduction by 50% in 2050 and an emission trajectory consistent with 450ppm concentration. The model has quantified other scenarios with the same emission trajectory but without additional gas availability. So, the BTL-GTL variant assumes the same broad context of global climate action as the rest of the decarbonisation scenarios.

The specific assumptions for the consumption pattern of the BTL-GTL variant concern primarily the transport sector. The "standard decarbonisation scenario" assumed the large scale electrification of the transport sector which requires large scale development of recharging infrastructure. The BTL-GTL variant addresses directly the possibility of continued use of conventional alternatives that do not necessitate massive upfront investment in infrastructure.

In order to compensate for this lack of flexibility concerning infrastructures the scenario mixes a number of assumptions in order to facilitate a meaningful response to policy challenges such as global warming and dependence on fossil oil. More specifically it is assumed that consumer preferences shift towards smaller and more efficient conventional vehicles and manufacturers respond by producing them at a reduced cost. In addition, the current scenario assumes breakthroughs in technologies associated with the use of lignocellulosic biomass for the production of biofuels-BTL (without making undue demand for land used for food production). Finally, the scenario assumes the development and high availability of gas-to-liquids (GTL) technologies (based on Fischer-Tropsch processes) and underpinned by an enhanced gas resource base (see below).

A key assumption of the scenario concerns increased resource availability for natural gas in the form of unconventional gas. Without such enhanced supplies the large scale introduction of gas to liquid conversion in the medium term would tend to transform an oil shortage into a gas one with obvious consequences for international gas prices thus neutralizing whatever potential advantages. The PROMETHEUS model treats tight sand gas as essentially conventional and therefore the scenario concentrates particularly on world prospects for shale gas which essentially dominate the uncertainty on commercial gas availability both in N. America (where the greatest amount of experience has been accumulated) and other regions of the World where considerable prospects are thought to exist.

The current shale gas “boom” is based on technical progress in terms of remote horizontal drilling and hydraulic fracturing used for increasing permeability around well bores. Such progress is given and is likely to continue, especially in the light of increased experience and prospects for shale gas. Furthermore risks of dry holes in shale are much lower than they are in conventional gas formations. On the other hand profitability of shale gas production is highly variable even within a single play and can only be properly established when a well is actually producing. This makes resource assessment particularly difficult especially when non-producing shales are considered. Experience in the US also suggests that there is a tendency for prospectors to exaggerate their prospects.

The assumptions about resource availability are based on the IEA "World Energy Outlook 2009"[66], in which about 40% of the resource endowment estimated in Rogner, H. H., 1997, "An Assessment of World Hydrocarbon Resources"[67] is assumed to become recoverable. This is equivalent to 180 tcm of shale gas and 24 tcm of coalbed methane. Such resources are furthermore assumed to become available at a cost of less than 250$`08 per tcm.

Although shale gas exploitation is being carried out in some areas of the world, environmental concerns over shale gas production have been raised. They have focused on two main areas: groundwater contamination and fugitive methane emissions.

Chemicals, notably benzene, are added to the water to facilitate the underground fracturing process that releases natural gas. Less than three quarters of the resulting volume of contaminated water is recovered and stored in above-ground ponds for removal. The remainder is left in the earth where it is feared it can lead to contamination of groundwater aquifers. On the other hand a 2011 study by the Massachusetts Institute of Technology[68] addressed groundwater contamination, noting "There has been concern that these fractures can also penetrate shallow freshwater zones and contaminate them with fracturing fluid, but there is no evidence that this is occurring". This study blames known instances of methane contamination on a small number of sub-standard operations, and encourages the use of industry best practices to prevent such events from recurring.

Methane is a very powerful greenhouse gas, although it stays in the atmosphere for only one tenth as long a period as carbon dioxide. Recent evidence indicates that methane has a global warming potential that is 105-fold greater than carbon dioxide when viewed over a 20-year period and 33-fold greater when viewed over a 100-year period, compared mass-to-mass. A 2011 study in Climatic Change Letters provides the first comprehensive analysis of the greenhouse gas footprint of shale gas. In that peer-reviewed paper, Cornell University professor Robert W. Howarth[69] and colleagues find that once methane leak and venting

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[66] "World Energy Outlook 2009 (WEO-2009), International Energy Agency, ISBN 978-92-64-06130-9, November 2009"

[67] Rogner, H. H., 1997,”An Assessment of World Hydrocarbon Resources”, Annual Review of Energy and Environment.

[68] MIT Energy Initiative (2011). "The Future of Natural Gas: An Interdisciplinary MIT Study". MIT Energy Initiative

[69] Howarth R.W., Santoro R, and Ingraffea A (2011). "Methane and the greenhouse gas footprint of natural gas from shale formations". Climatic Change Letters, DOI: 10.1007/s10584-011-0061-5

impacts are included, the life-cycle greenhouse gas footprint of shale gas is far worse than those of coal and fuel oil when viewed for the integrated 20-year period after emission. On the 100-year integrated time frame, which is most frequently used in UNFCCC negotiations, this analysis finds shale gas comparable to coal and worse than fuel oil. This is a serious indictment of shale gas in a strong climate policy context. On the other hand fugitive methane emissions are also important in the case of conventional gas and the scenario although implying a Worldwide decarbonisation effort is only concerned explicitly with CO_2 (50% Emission reduction Worldwide between 2005 and 2050).

13.1.1 Key results of the BTL-GTL scenario as implemented using the PROMETHEUS World energy model

As mentioned in the introduction, the BTL-GTL scenario is a variant of the standard decarbonisation scenario, the differences concerning primarily assumptions on the availability of gas resources and on the transport sector. Table 83 below summarizes the differences in results concerning the World transport sector.

Table 83: World energy consumption in transport; differences between the GTL scenario and the standard decarbonisation scenario with the Prometheus energy model (global values)

(Mtoe)	**2010**	**S.D. scenario**			**GTL-BTL scenario**			***Change from S.D. scenario***		
		2020	**2030**	**2050**	**2020**	**2030**	**2050**	***2020***	***2030***	***2050***
Total	**2320**	**2712**	**3102**	**3627**	**2756**	**2973**	**3739**	***43.7***	***-128.2***	***112.4***
Oil	2247	2604	2625	1549	2604	1927	718	*-0.3*	*-698.1*	*-831.1*
Biofuels	74	107	344	934	151	528	1634	*44.2*	*183.2*	*700.8*
GTL	0	0	0	0	0	514	1246	*0.0*	*514.3*	*1246.0*
Electricity	0	0	131	1056	0	4	70	*-0.2*	*-126.8*	*-985.5*

The standard decarbonisation scenario relies heavily on electrification of road transport in order to improve the efficiency of fleets and decarbonise the transport sector, whereas in the BTL-GTL variant the techno-economic development of electric vehicles and the development of the recharging infrastructure is assumed to be more limited. Electricity consumption for road transport, compared to the standard decarbonisation, registers a 127 Mtoe reduction already in 2030 building up rapidly to a 629 Mtoe reduction by 2040 and is close to 1000 Mtoe lower by 2050. Biofuels and GTL increase their shares substantially by scenario design. This increase occurs in the road transport sector as well as in air and maritime transportation. Such penetration is large enough to reduce oil consumption by a further 1000 Mtoe in 2050 in the BTL-GTL scenario compared to the standard decarbonisation scenario (S.D. scenario), although the transport sector does not electrify. The increased vehicle efficiency and the shift towards smaller vehicles assumed in the BTL-GTL scenario is enough to neutralize broadly the impact of the absence of a massive introduction of inherently more efficient plug-in hybrid and electric vehicles.

The massive introduction of GTL in the BTL-GTL scenario leads worldwide to much higher emissions (+1484 Mtn of CO_2) in the transport sector. Since the emission budget in the two scenarios is identical this means that reductions in emissions must occur elsewhere. The key sector for the shift is power generation. The lower demand for electricity accounts for about 2/3 of the reduction in emissions from power generation. The remaining is mostly achieved through shifts in power generation mix notably a 9% reduction in share of coal and gas generation with CCS in the later years of the forecast horizon and a 3% increase in fuel cell contribution in the same period (with hydrogen being primarily produced by biomass with CCS). Hydrogen apart, the BTL-GTL scenario implies slow development of all new power generation options beyond 2030 due to reduced requirements for new capacity. Table 1 below summarizes the CO_2 emission balance between the two scenarios for 2050 at a World level.

Table 84: World CO_2 emissions in 2050: difference between the GTL and the standard decarbonisation scenario in Mtn of CO_2

GTL-BTL scenario					
(MtCO2)	**Oil**	**Gas**	**Coal**	**Biomass**	**Total**
Transport	2758	3769	0	0	**6526**
Residential	605	606	1	0	**1212**
Industry	777	1852	1236	0	**3865**
Power generation	10	1503	879	-1165	**1227**
Hydrogen production	0	1	0	-2253	**-2251**
Other (incl. bunkers)*	513	2268	347	0	**3128**
Total	**4663**	**9999**	**2462**	**-3417**	**13707**
* primarily the energy sector					
S.D. scenario					
(MtCO2)	**Oil**	**Gas**	**Coal**	**Biomass**	**Total**
Transport	5042	0	0	0	**5042**
Residential	759	799	2	0	**1559**
Industry	811	1909	1371	0	**4090**
Power generation	10	2257	1761	-1616	**2412**
Hydrogen production	0	4	1	-2027	**-2022**
Other (incl. bunkers)*	1015	976	634	0	**2625**
Total	**7636**	**5944**	**3769**	**-3642**	**13707**
difference between the GTL-BTL and the S.D. scenario					
(MtCO2)	**Oil**	**Gas**	**Coal**	**Biomass**	**Total**
Transport	-2284	3769	0	0	**1484**
Residential	-153	-193	-1	0	**-347**
Industry	-34	-57	-135	0	**-226**
Power generation	0	-753	-882	451	**-1185**
Hydrogen production	0	-3	-1	-226	**-230**
Other (incl. bunkers)*	-502	1292**	-287	0	**503**
Total	**-2973**	**4055**	**-1306**	**225**	**0**
* primarily the energy sector					
**808 Mtn of CO2 represent emissions specifically associated with the gas to liquid conversion					

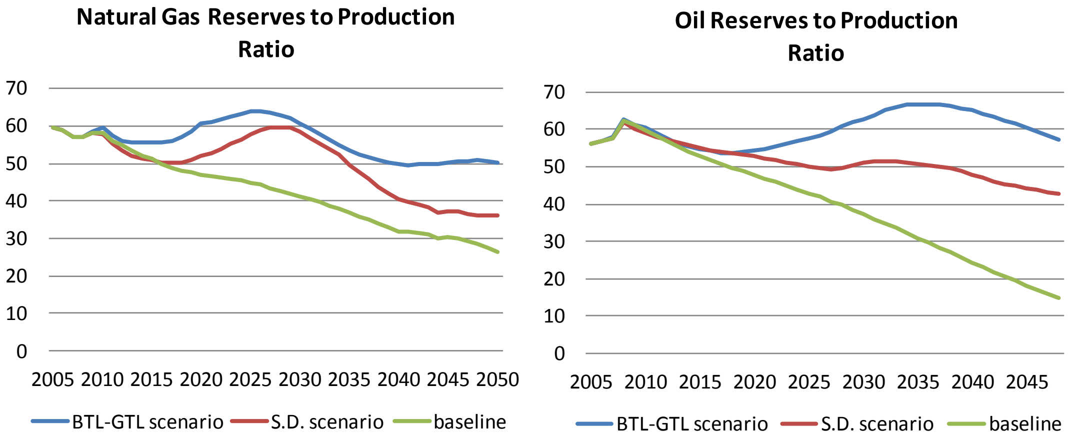
The BTL-GTL scenario clearly implies an increase in gas use boosted as it is both from the availability of additional unconventional resources and the widespread introduction of gas to liquids transformations. These substitutions in the transport sector together with the higher implicit carbon values mean that oil consumption between 2035 and 2050 is around 20% lower Worldwide compared to the S.D. scenario despite the lower oil prices obtained in the BTL-GTL scenario. Coal consumption is primarily affected by the earlier increases in effective carbon values, the lower electricity production beyond 2030 with particularly strong impacts on coal fired power generation using CCS. Figure 2 illustrates graphically these findings.

Table 85: World primary energy consumption;

(Mtoe)	2010	S.D. scenario			GTL-BTL scenario			Change from S.D. scenario		
		2020	2030	2050	2020	2030	2050	2020	2030	2050
Oil	4218	4753	4742	4006	4749	3941	3324	-4	-801	-682
Coal	3443	3408	1502	2456	3205	1313	1363	-203	-189	-1093
Gas	2888	3481	3226	4455	3506	4116	5670	24	890	1216
Total fossil fuels	10549	11642	9470	10916	11459	9370	10357	-183	-100	-559

The results on primary production reflect strongly on the results obtained for reserves to production (R/P) ratios which are a good overall measure of security of supply implications of the scenario. The enhanced natural gas endowment means that there is an early improvement in R/P ratios. Between 2020 and 2030 a great part of the differential in R/P ratios is eroded due to the rapid uptake of new gas for conversion to liquids. Beyond 2035 as the market for GTLs gradually begins to saturate the increasing discoveries of shale gas mean that R/P ratios differentials pick up again. Broadly speaking, the BTL-GTL scenario implies that throughout the forecast period there is little change in the present World gas supply-demand situation. This is certainly not the case in the baseline projection but also with the S.D. scenario for the period beyond 2035.

Figure 24: Natural gas and oil R/P ratios in baseline, standard decarbonisation and BTL-GTL scenario



Results for the global petroleum R/P ratio are also very interesting. The baseline is characterised by a continuous drop from around 60 years of projected resource availability in 2010 to 40 years in 2030 and a barely sustainable 15 years by 2050. The S.D. scenario resulted in a slight drop to 50 years in 2030, stabilization around that level until 2040 and a small decline to 43 years by 2050. The considerably lower demand for oil in the BTL-GTL scenario leads to an increase in oil R/P ratios between 2020 and 2035 from 54 to 66 years and a slight decline to 60 years by the end of the projection period. Such higher R/P ratios generally imply more flexible oil markets and reduced vulnerability to oil supply disruptions and subsequent oil price shocks.

13.1.2 Production of natural gas

The table below summarises the impact of the BTL-GTL scenario on the production of natural gas in the different regions[70] identified in the PROMETHEUS model.

Table 86: Production of natural gas in Prometheus regions in bcm

	2008	S.D. scenario			BTL-GTL scenario			% change from S.D. scenario (2050)
		2020	2035	2050	2020	2035	2050	
Europe	318	225	172	96	226	231	147	53%
North America	750	594	651	500	605	846	661	32%
OECD-Western Pacific	53	75	126	160	76	176	206	29%
China	80	147	199	229	148	268	291	27%
India	32	80	109	133	80	124	144	8%
CIS	850	989	713	656	997	1263	1190	81%
MENA	551	865	987	1495	866	1165	1645	10%
Emerging Economies	410	617	795	1111	621	859	1393	25%
Rest of the world	123	202	323	476	202	362	505	6%
World	**3167**	**3795**	**4076**	**4856**	**3821**	**5294**	**6181**	**27%**

The S.D. scenario registers marked slowdown in natural gas production between 2020 and 2035 as climate policy related measures begin to take strong effects in most regions of the world. This situation is radically reversed in the BTL-GTL scenario because of the build-up of the gas to liquids conversion during that period in response to scenario assumptions. By 2050,

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[70] The regions of the PROMETHEUS model are broadly defined as follows:

Europe	the 27 current members of the European Union + Switzerland and Norway
North America	the USA and Canada
OECD-Western Pacific	Japan, Australia, New Zealand, South Korea
China	China (including Hong Kong)
India	India
CIS	the Former Soviet Union excluding the Baltic Republics
MENA	the Middle East (from the Mediterranean to the Iranian border with Afghanistan and Pakistan) and North Africa (Egypt, Libya, Tunisia , Algeria, Morocco)
Emerging Economies	Emerging economies includes all other countries that had more than 3000 ($95) PPPs per capita in 2000. Broadly speaking this region includes Turkey, almost the whole of Latin America, Southeast Asia (excluding Indonesia and Indochina) and Southern Africa.
Rest of the world	All other countries . This includes most of the rest of Africa. Big economies in this category are Pakistan, Bangladesh, Vietnam and Indonesia.

world gas consumption/production in the BTL-GTL scenario stands 27% above S.D. scenario numbers.

The largest proportion of this increase occurs in the CIS region. Though richly endowed with gas resources, this region sees a dramatic reversal in the S.D. scenario from 2020 onwards with production falling sharply between 2020 and 2035 and standing at a level 23% lower in 2050 compared to 2008. The main reason for this development is the need to reduce domestic consumption of natural gas in order to meet stringent CO2 emission constraints: gas dominates consumption patterns in CIS to such an extent that GHG emission reductions inevitably imply lower consumption of natural gas. In addition, Europe which is traditionally the largest CIS gas export market also reduces gas consumption in response to climate policies. The BTL-GTL scenario means that demand picks up in both these markets. Furthermore, Russia is richly endowed with good shale prospects in regions that though remote are already gas producing thus lightening the burden of excessive additional infrastructure requirements. The GTL boom worldwide also implies that CIS resources (conventional or shale) can reach remote and virtually inaccessible world markets in the form of gas derived liquid fuels. Strong shale prospects in Argentina, Brazil and Mexico produce to a considerable extent the large increase registered in Emerging Economies. North America is already assumed to produce a large portion of its gas from shales in the baseline and S.D. scenarios. The increases in the BTL-GTL scenario therefore are relatively modest but still sufficient to maintain virtual gas self-sufficiency in the region despite the large increase in gas requirements for the transport sector. The MENA region which in the S.D. scenario becomes the dominant player in gas international trade also sees a significant increase in volumes of gas produced, GTL production affording a cheaper and more flexible way of marketing gas in remote parts of the planet.

Table 87 summarises the impacts of BTL-GTL scenario in production of oil in the different world regions.

Table 87: Production of oil in Prometheus regions in mb/d

		S.D. scenario			**BTL-GTL scenario**			**% change from S.D. scenario (2050)**
		2020	**2035**	**2050**	**2020**	**2035**	**2050**	
Europe	4.7	2.6	1.0	0.5	2.6	0.8	0.4	-20%
North America	11.1	11.9	11.0	8.6	11.8	8.6	7.0	-19%
OECD-Western Pacific	0.7	0.7	0.4	0.3	0.7	0.3	0.2	-19%
China	4.0	4.0	2.0	0.8	4.0	1.6	0.6	-21%
India	0.8	0.9	0.7	0.4	0.9	0.5	0.4	-20%
CIS	13.7	15.2	13.1	9.3	15.2	10.4	7.7	-18%
MENA	29.6	38.5	40.3	44.5	38.4	32.9	37.4	-16%
Emerging Economies	11.6	14.1	12.1	11.1	14.1	9.4	8.9	-19%
Rest of the world	8.3	8.1	6.6	5.2	8.0	5.3	4.4	-16%
World	**84.4**	**95.7**	**87.2**	**80.7**	**95.6**	**69.8**	**66.9**	**-17%**

According to this scenario, world production peaks just after 2020 and declines sharply between 2025 and 2035. In 2050 world oil demand according to this scenario will be 21% lower than 2009 levels and 17% lower than S.D. levels.

As mentioned earlier in the discussion on Reserves to Production ratios the BTL-GTL results in a considerably easier world hydrocarbon demand-supply situation thus reducing the risk of damaging disruptions. This constitutes a major gain arising from the scenario, as apart from the reduction of risk of strong and damaging price shocks, it also gives the world energy system additional years in which to eventually adjust to a post fossil fuel future. On the other hand PROMETHEUS results suggest that the scenario does not overall lead to reduced relative dependence on traditional hydrocarbon exporting parts of the world. This arises from the fact that on the one hand unconventional gas prospects are not necessarily better distributed than conventional ones and in fact in a way reproduce existing hydrocarbon occurrence patterns and on the other GTL conversion offers a means by which geographic concentration of conventional and unconventional resources can be better translated into market power in a more globalised energy system.

13.2 EU GTL Transport Scenario

The GtL transport scenario quantified with the PRIMES-TREMOVE transport model assumes that GtL is imported into the EU and that the GtL can be used as a perfect substitute to diesel and gasoline produced from crude oil. This scenario assumes an almost total failure in the development of electric and fuel cell vehicles, with only a very slight development above Reference scenario levels.

This scenario assumes nonetheless the achievement of the 60% emission reduction target for the transport sector. This scenario is assumed under the assumption of failure of electro-mobility either due to lack of sufficient techno-economic development or the lack of development of the sufficient infrastructure to allow large scale development of electro-mobility. Further this scenario assumed the abundance, as explained above of large amounts of natural gas. Under these circumstances the model was used to quantify a scenario with the remaining options. The quantification of this scenario resulted in the use of additional biomass; analysing this result with the biomass supply model it resulted that the majority of this additional biomass would have to be imported. Considering a context of global climate mitigation action, it could be contested whether this additional amount can be imported from sources complying with sustainability criteria. Therefore a further variant of the scenario was quantified limiting the availability of biomass to the amounts quantified in the dominant biomass scenario which are compliant with strict sustainability criteria. The only options thus remaining to obtain the 60% emission reduction target are modal shifts and reduction of activity through strict policy measures, options which were not analysed in the other cases of this study. The two variants were quantified analysing these two options to achieve the 60% emission reduction target with the PRIMES-TREMOVE transport model; summary results are presented below.

13.2.1 Key results of the GTL transport scenario variants

In the following the key results of the two sensitivity scenarios with GtL are presented; the results refer to the EU27. The scenario with no constraint on biomass use is named GtL with high BtL scenario and the scenario with a constraint on the availability of biomass resources is named GtL-biomass constraint. It is reminded that the two scenarios have the same techno-economic assumptions for all technologies. The changes between the scenarios relate to the prices of biofuels – higher in the biomass constraint-, and the carbon values used as a residual variable to achieve the 60% emission reduction target –higher in the biomass constraint scenario.

The dominant biomass scenario case, as the Reference scenario, has rising activity levels compared to 2005 and the activity levels in 2050 are only slightly lower than the Reference scenario. The GTL with high BTL sensitivity sees slightly lower activity levels compared to the dominant biomass due to higher prices of fuels, whereas the GTL-biomass constraint sensitivity sees a considerable drop in activity. This considerable drop in activity is due to the limitation in biomass availability and strong policy measures imposed to achieve the 60% emission reduction target. The availability of only conventional ICEs and hybrids, due to the complete failure of any form of electro-mobility, limits the options to reduce emissions in transport. The only available option to reduce emissions, the use of biomass fuels, is limited; therefore the only remaining options are modal shifts or reduction of activity, as can be observed in the results of the GTL-biomass constraint scenario.

Table 88: Levels of activity in the dominant biomass and the two GTL scenario variants

					GTL			
			Dominant biomass		GTL with high BTL		GTL-Biomass constraint	
		2005	2030	2050	2030	2050	2030	2050
Passenger transport activity	**Gpkm**	**6240**	**8163**	**8997**	**8123**	**8867**	**7942**	**8034**
Private Road	% shares	75.1	70.6	68.4	70.5	68.0	69.7	65.3
Public Road		8.4	7.8	7.7	7.8	7.7	8.1	9.3
Rail		7.4	7.9	8.9	8.0	9.0	8.3	10.7
Aviation		8.4	13.1	14.4	13.2	14.7	13.4	14.0
Inland Navigation		0.6	0.6	0.6	0.6	0.6	0.6	0.7
Freight transport activity	**Gtkm**	**2495**	**3382**	**3705**	**3370**	**3614**	**3345**	**3515**
Road	% shares	72.2	71.5	70.4	71.3	69.4	70.9	67.0
Rail		16.6	18.1	18.9	18.2	19.7	18.4	21.0
Inland Navigation		11.2	10.5	10.6	10.5	10.9	10.7	12.0

The stock of passenger cars and LDVs changes considerably compared to 2005 and represents a substantially different result from the previous scenario-cases analysed within this study. By 2050, in the GTL scenario 61% of cars and LDVs are still conventional ICEs or hybrid vehicles; with hybrid vehicles representing 34% of the total stock of cars and LDVs (by comparison they only represented 17% of the vehicle stock by 2050 in the dominant biomass case); in the GTL-biomass constraint scenario the structure of vehicles is very similar but the overall number of vehicles decreases due to lower activity levels. The scenario assumes complete failure of the development of electric vehicles in any form including plug-in hybrids. The dominating vehicle form with 34% of stock share is the hybrid vehicle, which although it is assumed to become more efficient than in the dominant biomass scenario, nonetheless remains by technology definition less efficient than PHEVs, BEVs or FCEVs.

Table 89: Stock of passenger cars and LDVs in the two GTL variants

(million vehicles)	2005	GTL with high BTL				
		2020	2030	2050	Difference from 2005	
					in 2030	in 2050
Diesel Conventional	87.6	87.4	52.2	33.8	-35	-54
Gasoline Conventional	150.4	130.4	86.8	50.8	-64	-100
Hybrid	0.0	33.7	85.0	105.6	85	106
LPG and CNG	5.6	21.8	35.9	44.8	30	39
Ethanol car	0.0	0.1	2.2	8.5	2	8
Plug-in Hybrid	0.0	11.4	25.0	42.0	25	42
BEVs	0.0	0.1	5.4	17.5	5	17
FCEVs	0.0	0.0	1.0	8.1	1	8
Total	**243.6**	**284.9**	**293.5**	**311.1**	**50**	**67**

(million vehicles)	GTL biomass constraint				
	2020	2030	2050	Difference from 2005	
				in 2030	in 2050
Diesel Conventional	87.1	51.1	31.2	-36	-56
Gasoline Conventional	129.3	82.8	44.7	-68	-106
Hybrid	33.3	82.5	94.8	82	95
LPG and CNG	21.7	35.4	38.9	30	33
Ethanol car	0.1	2.4	9.1	2	9
Plug-in Hybrid	11.5	25.0	36.4	25	36
BEVs	0.1	5.4	14.5	5	14
FCEVs	0.0	1.0	6.7	1	7
Total	**283.1**	**285.6**	**276.3**	**42**	**33**

Compared to the dominant biomass scenario, final energy demand for the entire transport sector is higher in the GTL variant because of the use of vehicle technologies that are by definition less efficient than those used in the dominant biomass scenario. The hybrid technology which dominates the car market in this scenario cannot compete in terms of fuel efficiency with PHEVs or BEVs, although the efficiency gains in the hybrid technology assumed are considerable. In the GTL variant with high BTL the use of less efficient technologies and the availability of additional biomass resources leads to higher final energy demand than in the dominant biomass case. In the GTL-biomass constraint variant the final energy demand on the contrary decreases compared to the dominant biomass; the reduction in activity due to the limited availability of biofuels leads to lower overall fuel consumption.

In terms of fuels consumed some shifts can be observed. Whereas the amount of biofuels remains almost the same between the dominant biomass and the GTL –biomass constraint, there is an increase in the GTL with high BTL variant, as this variant does not limit the availability of biomass. Electricity and hydrogen consumption in the GTL scenarios remains marginal, whereas it represented a more substantial share in the dominant biomass case. The major difference between the scenarios is the residual amount of oil products used in the different variants. Whereas in the dominant biomass 41% of final energy demand refers to oil products, in both the GTL variants the share of oil products decreases to 17% and 19% in the GTL with high BTL and GTL with biomass constraint variants respectively. This further reduction in oil product consumption compared to the dominant biomass scenario is caused by the availability of GTL at approx. the same prices as the oil products used in transport i.e. diesel and gasoline.

Table 90: Final energy demand in the transport sector for the two GTL variants

(Mtoe)	Dominant biomass				
	2005	2020	2030	2040	2050
Oil products	352	329	264	191	104
Natural Gas	1	4	9	10	9
Biomass	3	29	45	71	112
Hydrogen	-	0	0	1	3
Electricity	6	9	13	18	23
GTL	-	-	-	-	-
Total	**362**	**372**	**332**	**291**	**251**

(Mtoe)	GTL with high BTL			
	2020	2030	2040	2050
Oil products	330	225	114	45
Natural Gas	4	10	11	14
Biomass	30	50	84	137
Hydrogen	0	0	1	3
Electricity	9	11	14	15
GTL	-	40	76	55
Total	**373**	**336**	**300**	**268**

(Mtoe)	GTL biomass constraint			
	2020	2030	2040	2050
Oil products	329	222	114	46
Natural Gas	4	9	9	9
Biomass	30	48	76	117
Hydrogen	0	0	1	2
Electricity	9	12	14	14
GTL	-	39	76	56
Total	**372**	**330**	**291**	**246**

Primary energy requirements do not change substantially between the scenarios, but reflect the higher or lower final energy demand in the different variants. The GTL with high biomass scenario has the highest primary energy requirements, due to its higher final energy consumption due to the use of less efficient vehicle technologies than in the dominant biomass case. The GTL biomass constraint scenario has lower primary energy consumption due to the lower final energy demand, caused by the lower activity levels which compensate for the lower efficiency of the vehicle technologies used. The structure of the primary energy supply will be different as there is a partial substitution of oil imports (crude oil and oil products) with GTL. This would have different implications for the import structure of the EU27.

Table 91: Primary energy requirements

(Mtoe)	Dominant biomass				
	2005	2020	2030	2040	2050
Oil and GTL	371.3	338.2	268.2	191.0	102.5
natural gas	5.2	12.3	18.1	19.9	17.2
biomass	3.7	31.8	49.6	76.8	119.2
solids	5.1	18.5	11.3	6.8	6.7
other RES	0.8	2.5	5.0	8.2	11.7
Nuclear	5.6	6.5	10.6	14.8	18.4
Total	**391.7**	**409.8**	**362.7**	**317.5**	**275.6**
(Mtoe)		GTL with high biomass			
		2020	2030	2040	2050
Oil and GTL		339.7	269.7	191.8	99.0
natural gas		12.1	18.0	19.3	19.9
biomass		31.9	53.4	88.9	143.1
solids		18.3	11.0	6.0	4.8
other RES		2.4	4.5	6.5	8.1
Nuclear		6.3	9.5	11.9	12.5
Total		**410.8**	**366.0**	**324.5**	**287.5**
(Mtoe)		GTL biomass constraint			
		2020	2030	2040	2050
Oil and GTL		338.1	266.0	191.3	102.2
natural gas		12.1	17.6	17.9	15.1
biomass		31.8	51.3	81.2	122.8
solids		18.3	10.9	5.9	4.5
other RES		2.4	4.5	6.4	7.4
Nuclear		6.3	9.5	11.6	11.4
Total		**409.0**	**359.8**	**314.3**	**263.6**

14 SWOT analysis[71]

14.1 Introduction

Based on the cases as formulated in the previous chapters and the resulting outcomes, a Strength, Weaknesses, Opportunities, and Threats (SWOT) analysis is carried out to provide a comprehensive social-economic comparison of the scenarios. The SWOT analysis discusses the strengths and weaknesses of the scenarios from an internal perspective, based on their specific input assumptions and functioning. The opportunities and threats are presented from an external perspective, based on general market conditions and constraints. Key SWOT indicators such as the technological feasibility, scalability, social and user acceptance of different vehicles are presented in detail for each scenario and taking into consideration the dominant fuel-technology combination. The main conclusions from the SWOT analysis for each scenario are then summarized in a table.

14.2 Technological feasibility

14.2.1 Technology perspective

Currently various automotive manufacturers (Honda, Toyota) are producing hybrid electric vehicles aiming at reducing the fuel consumption and CO_2 emissions. Innovative technology options are included such as regenerative braking which allow the small electric motor to assist the ICE and thus improve the fuel economy of the vehicle. PHEVs on the other hand are designed in such a way that both the electric motor and the ICE can operate separately; PHEVs offer full electric range possibility which depends entirely on the battery capacity. The cost and the weight of the batteries are therefore of crucial importance for the electric range of the PHEVs; such vehicles are particularly seen as mid-term transition solution towards BEVs or FCEVs (Safarianova et al., 2011). BEVs would demand high energy density batteries that fit a vehicle platform and provide an acceptable driving range (> 100 km). Although Li-ion batteries are currently considered as an attractive option for electric vehicles, other potential materials might be discovered in the future which might deliver higher energy capacities.

Howey et al. (2011) compared the energy consumption and CO_2 emissions of 51 BEVs, HEVs and ICEs under real world driving conditions. As regards the fuel consumption, BEVs are the most efficient due to a powertrain efficiency of about 90% while ICEs are the least efficient. As far as the carbon intensity of each vehicle is concerned, the carbon footprint of the BEVs should be calculated on a WTW basis, thus taking into account the grid's average CO_2 intensity. BEVs could lead to a high reduction in the CO_2 emissions in the transport sector once their electricity demand is met with low-carbon or carbon-free power generation processes.

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[71] Section prepared by ECORYS

Hydrogen also enables diversification from petroleum products and reduces the dependency on oil. FCEVs like the BEVs have zero tailpipe emissions; their WTW CO_2 emissions though depend on the hydrogen production processes. If hydrogen is produced from non-GHG emitting sources, a FCEV is capable of near-zero WTW emissions (Kromer & Heywood, 2007). FCEVs have a number of practical constraints in real operation. The membranes and catalysts in use today affect the performance and durability of the fuel cell stack[72]. Limited operating lifetime and durability of fuel cells are a main challenge to commercialization of these vehicles. While an operating life of 5,000-5,500 hours with 17,000 start/stop cycles is required from automotive industry perspective, currently fuel cells only provide 2,000 hours of lifetime (Safarianova et al., 2011); other studies however indicate that individual cells and short stacks have demonstrated higher load-hour capacity in the laboratory environment (Steinbugler, 2006). At the vehicle level, storing enough hydrogen (which has low volumetric energy density) to allow for an adequate vehicle range, is problematic.

14.2.2 Fuel perspective

Many fuel options are technically and commercially available, such as bioethanol from sugarcane or wheat, biodiesel from rapeseed, HVO (palm), CNG, LPG, FT diesel/GTL (NG), hydrogen (NG), and hydrogen (wood). Others, such as bioethanol (wood), Bio-SNG, BTL and wood hydrogen, require considerable research and development. Among those, lignocellulosic ethanol may be closer to technology readiness due to the large research funding it has already received, and due to the existing research efforts (Schwietzke et al., 2006; Lynd et al., 2008). Low carbon content fuels seem to be a promising option to achieve CO_2 emission reduction. However, as regards biofuels, incompatibility issues might be raised as currently not all possible biofuels mixtures are certified for spark and compression ignition engines specifications.

14.2.3 Refuelling and recharging infrastructure

Massive diffusion of BEVs and PHEVs would require investments in developing the necessary recharging infrastructure; slow and fast recharging points would be required in order to accommodate the demand for electricity. Apart from the recharging outlets, the strengthening of the existing electricity distribution grid seems to be very important (Vliet, 2010). Vliet (2010) indicates that uncoordinated charging would increase the Dutch national peak load by 7% and household peak load by 54% (which may exceed the capacity of existing electricity distribution infrastructure)[73]. On the contrary, the study suggests that off-peak charging would result in a 20% higher, more stable base load and no additional peak load at a national level and up to 7%

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[72] A fuel cell converts the chemical energy into electric energy. A single fuel cell is only capable of producing about 1 volt, so typical fuel cell designs link together many individual cells to form a 'stack' to produce a more useful voltage. A fuel cell stack can be configured with many groups of cells in series and parallel connections to further tailor the voltage, current, and power. The number of individual cells contained within one stack is typically greater than 50 and varies significantly with stack design (http://www.nfcrc.uci.edu).

[73] A 30% penetration rate of BEVs is assumed.

higher peak load at the household level. He argues that if off-peak charging is successfully introduced, electric driving need not strain infrastructure, even in case of 100% switch to electric vehicles.

A Danish model (EnergyPLAN) study (Lund & Kepton, 2010) analyzed the implementation of large-scale sustainable energy systems. By adding ‘‘vehicle-to-grid’’ (V2G)[74] technology to BEVs – sometimes referred to as ‘‘smart charging” – it can provide storage, matching the time of generation to time of load. V2G power technology is one of the many energy storage technologies, which may be part of making a flexible energy system that can better utilise fluctuating renewable energy sources. The study found that adding EVs and V2G to these national energy systems allows the integration of much higher levels of wind electricity without excess electric production, and also greatly reduces national CO_2 emissions.

V2G provides several benefits to the transportation and electricity industry and to society. It could assist in achieving benefits to the transportation system by reducing petroleum use, strengthening the economy, enhancing national security of energy supply, reducing strain on petroleum infrastructure, and improving the natural environment. For electricity, it could assist in achieving benefits by providing a new demand for electricity, ideally during the parts of the day when demand remains low. Furthermore, it could add capacity to the electric grid during peak times without the need for the utility industry to build new power plants.

Developing a robust hydrogen refuelling infrastructure is widely considered among the steepest challenges developing a hydrogen-based road transport sector (Kromer & Heywood, 2007). First, high production volumes are needed to drive the cost reductions that will enable market-competitive FCEVs. However, the levels of investment required to achieve these production volumes are unlikely to proceed without a clear path to market competitive vehicles. Second, industry awaits consumer demand while consumers are unwilling to purchase FCV’s without access to refuelling infrastructure. Finding a path to transition from a narrowly-defined niche to a broad-based consumer market is a huge challenge: previous experience with natural gas vehicles suggests that moving from an urban niche market to the population at large requires an investment in infrastructure outside of population centres that is not justified by the consumer demand without additional support. This suggests that developing a robust hydrogen refuelling infrastructure (production, distribution and storage) will require extensive policy support.

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[74] V2G is built on top of (plug-in) electric vehicles (EVs). V2G refers to adding the capability to deliver power from the vehicle to the grid, but V2G is also used to imply that power flow, whether to or from the vehicle, is controlled in part by needs of the electric system, via a real-time signal (Lund & Kempton, 2008).

14.3 Scalability

14.3.1 Technology perspective

HEVs are currently in the market, and no particular scalability issue exists. However, as these vehicles require high power density batteries which are more likely to be Li-ion batteries, resource limitations in materials could become a challenge. Li-ion batteries' specific costs are expected to decrease through economies of scale. However, mass production would cause Lithium scarcity as its proven resources are limited and this would significantly affect the material costs. Several studies (Evans, 2008; Yaksic & Tilton, 2009) argue that despite the inherent uncertainties regarding the current and future lithium availability as well as the uncertainties about the future cost-reducing effects of new production technologies, concerns regarding lithium availability for hybrid or electric vehicle batteries or other foreseeable applications seem to be unfounded. However, other studies (MIR, 2008; Tahil, 2010) raise a number of concerns such as:

- realistically achievable lithium carbonate production will be sufficient for only a small fraction of future PHEV and BEV global market requirements;
- demand for lithium from portable electronics sector will compete with demand for lithium for BEVs' battery manufacturing;
- lithium reserves are lower than previously estimated;
- production of lithium carbonate is not environmentally sound. It is said to cause irreparable ecological damage to ecosystems which is incompatible with the notion of 'green car';
- the highly focused geographical concentration of lithium production is a risk to the, in some cases, already strained geopolitical relations between countries and regions.

The main challenge for BEVs for acquiring a large market share are battery costs, the range limitation, and the use of unconstrained resources. Last but not the least, vast investments on battery capacity enhancements and charging stations is needed to make battery electric vehicles' market penetration feasible.

14.3.2 Fuel perspective

Biofuels scalability estimations are associated with high uncertainties regarding the population growth, food demand and development of food production potential and land use in future. The future availability of biomass for energy purposes depends on the amount of land that is not needed for food production (non-food areas). Grahn et al. (2009) analyzed the role of biofuels for transportation in various long-term CO_2 emission reduction scenarios with global versus regional carbon caps. Results show that biofuels could hold a significant role, but are not likely to play a dominant role in the transportation sector (21% share in the most optimistic scenario).

The potential deployment of hydrogen as an energy carrier in the road transport sector depends on the development of vehicle and distribution infrastructure. Large scale hydrogen production processes should take into account economic, technical and environmental considerations. Currently, hydrogen production is mainly achieved through steam reforming of natural gas and coal gasification. Hydrogen from biomass gasification on the other side is environmentally promising but it is not technically mature yet; the sustainability of biomass feedstock should also be assured. Hydrogen production through electrolysis could become largely available in the future and provided that electricity used is generated from low carbon processes, then the CO_2 impact of hydrogen production could be diminished.

14.3.3 Refuelling and recharging infrastructure

Many sources in literature argue that the technological constraints or barriers for the transition to an electro-mobility future are limited. Several studies indicate that the main barriers for developing the necessary electricity recharging and hydrogen refuelling infrastructure have economic and socio-political foundations (Delucchi & Jacobson, 2011; Williams & Kurani, 2006; Meyer & Winebrake, 2009).

14.4 Social acceptability

Social acceptability is considered among the most important factors for the successful penetration of a new technology in the market. As a matter of fact, low social acceptance of a technology could prove detrimental to its market diffusion despite its cost competitiveness. The social acceptability is defined for three actor types (Wuestenhagen et al., 2007): the policy makers, the stakeholders and the public. As regards the stakeholders, their aim is to promote their own benefits such as the diffusion of a new technology in the transport sector. As a result, the policies adopted could have a positive (e.g. subsidization) or negative impacts (taxation) on their fields of interest. From a public point of view, the acceptance criteria are different. The public is mainly interested in the social effects of the introduction of a new technology which include the increase in the welfare, the reduction of externalities such as pollution, noise, accidents and congestion. The new technologies should lead towards less noise and accidents and thus reduce the related external costs.

The social acceptability is analysed by using indicators such as the social equity effect, the internalization effects and the employment generation. More specifically, *social equity* defines whether the user costs are significantly higher to the disadvantage of lower-income groups. This effect is expected to be present in non-mature technologies where the production costs are usually higher. Additionally, the social equity dimension assesses the level of access equity. This can prove to be a significant factor for user acceptability due to the limitations of new technologies (e.g. range limitations of BEVs). As an example, people that live in urban areas benefit from the availability of fuel-providing infrastructure while people in rural areas do not have the same access to such commodities (e.g. less dense network of hydrogen retail stations in rural areas).

Another important social effect is the *generation of new jobs or the shifting of jobs* as a result of new research, development, production and innovation activities. S*ocial awareness* of the end-users indicates the availability of information for the new technologies as well as other policy measures which could be beneficiary to the consumers. The following subsections explore the aforementioned social criteria. Other criteria such as the GDP per capita and the oil price could also influence the social acceptability.

14.4.1 Technology perspective

Although new vehicles technologies could be commercially available in the short term, Brown et al. (2008) argue that a wider diffusion of such technologies appears to be impeded by barriers such as their high investment costs, lack of information about the availability and benefits of these technologies and regulations that hinder their entrance in the market. The high cost of the original investment such as the battery cost of a BEV or the fuel cell of a FCEV results in social inequities. High investment costs, if not subsidised, imply a negative effect on low-income users. Various schemes have been proposed to tackle the high battery costs including policy incentives, battery leasing and battery reuse and recycling (Wiederer & Philip, 2010).

The large scale deployment of hybrid, BEVs and FCEVs is expected to increase the job opportunities in car manufacturing, transport infrastructure as well as battery, fuel cell and power electronics production (Safarianova et al., 2011). As regards the noise, BEVs and FCEVs due to their electric operation are silent; especially in the urban areas a potential noise reduction could imply increase in the social acceptability of such vehicles. Hence, it is substantial to provide a policy aid framework (Sovacool & Hirch, 2009) in order to increase social awareness and shift the market interest towards cleaner and more efficient technologies.

14.4.2 Fuel perspective

Biofuels can be produced from a wide range of biomass feedstock; however the production of 1st generation biofuels requires efficient land use and need to comply with strict sustainability criteria. Competition with food production could have a negative impact on the social acceptance of 1st generation biofuels which is due to the fact that the land used for food production is now used for energy crops production. The economic viability of the 2nd generation biofuels needs to be reassured before their large-scale deployment takes place.

These points of criticism were partially tackled by the EC by setting a 10% target by 2020, specifying that at least 40% of the 2020 goal must be met from "non-food and feed-competing" second-generation biofuels or from cars running on green electricity and hydrogen (EurActiv 12/09/08 – ref 2).

As regards CNG, LPG and hydrogen vehicles, issues are frequently raised with respect to their tank safety; however studies (Safarianova et al., 2011) suggest that current regulations on fuel tank safety do not raise safety risks.

14.4.3 Refuelling and recharging infrastructure

In refuelling and recharging infrastructure, the most important social aspects are social equity, security of supply - reliability, accessibility and safety.

Regarding the BEVs, according to Van den Bossche (2010) overnight battery recharging raises no problems to the consumers. However, a study produced by CITELEC[75], the association for European Cities interested in BEVs, revealed that reliability issues may occur for individuals due to the fact that transformers fitted could induce overload. As regards accessibility to the charging points it seems that in the urban areas recharging infrastructure could develop at a larger extent while in the rural areas the development of the necessary infrastructure could develop at a slower pace; the density of the recharging infrastructure in the rural areas therefore might be lower than in the urban areas.

Recharging time is also an important factor for the acceptability of the BEVs (Wiederer & Philip, 2010). Currently, recharging from a slow charging point takes approx. about 8 hours. Such charging time for an overnight charging or charging at the working parking lot seems acceptable, nonetheless in all other cases could be very inconvenient. Other methods such as battery swapping could offer significant time reduction compared to the duration of recharging; however studies argue that such methods might not be publicly accepted (Accenture, 2011).

14.5 User acceptability

User acceptability is related to the personal preferences of the end-users, contrasting the social acceptability which is defined in a broader sense including also benefits to the society. User acceptability could be influenced by technological aspects, the comfort level, the limitations induced by the use of a specific technology, the personal needs and the intensity of the capital cost. The level of user acceptability is a very important factor in the adoption of a new technology. For instance the limitations implied by the BEVs regarding the vehicle range could deter a potential consumer from purchasing such a vehicle even though the latter has become cost-competitive.

14.5.1 Technology perspective

The consumer preferences in the case of hybrids, plug-in hybrids and battery electric vehicles are mainly influenced by the technical limitations of these vehicles; even though the socio-economic benefits from them could be quite high, their market penetration might be hindered without the expected progress.

Several studies have so far explored the main elements behind the adoption of hybrids, PHEVs and BEVs. Axsen et al. (2009) claimed that the user acceptability is a combination of *financial attributes* (capital and operational/ maintenance costs) and *intangible costs* such as consumer perception of quality, reliability, social desirability etc. Mau et al. (2008) attempt to quantify the purchasing behaviour taking into consideration the *policy influences*. Turrentine & Kurani (2007) emphasise on *fuel efficiency* and its relation to consumers’ willingness-to-pay. Common attributes to all studies are the attributes of range limitations, the capital and other costs, the performance and the appointed subsidies.

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[75] http://www.citelec.org/en/

In terms of capital costs, BEVs and FCEVs currently are all far more costly than conventional ICE powertrains. As soon as these technologies become cost-competitive to the ICEs, then the significant gains in fuel cost savings might prove an important factor for the consumers to purchase these vehicles (Offer et al., 2010). A possible subsidization of the BEVs or the FCEVs could probably enable a wider diffusion of such technologies and at a higher pace.

One important conclusion from Turrentine & Kurani (2007) is that the users' behaviour as regards the adoption of new vehicle technologies is highly influenced by the fuel economy perception (bounded rationality leading to irrational choices). The main threat coming from this point is that a considerable part of the consumers do not have enough information on the potential fuel saving of using such vehicles. The study also mentions that in particular the positive impact of such vehicles on the environment could drive their wider deployment in the market.

In terms of technical limitations for BEVs, the driving range as well as the battery lifetime and their related attributes are the main constraints. The range limitation could prove a detrimental factor for the diffusion of the BEVs and their dominance in the car market. Even though the range currently provided by the manufacturers of the BEVs seems to be sufficient for the urban environment transportation needs including commuting or working trips, it is not sufficient for the inter-urban areas and long-distance highway trips. This constraint could be a disadvantage compared to the conventional ICEs which do not pose range limitations. Additionally, the lower density of recharging infrastructure in other than urban areas such as rural ones and the charging duration could have negative effects on the consumers' acceptability. As regards the hybrid vehicles, studies (Safarianova et al., 2011) argue that the inactiveness of heating/ air-conditioning while the vehicle is stopped could influence negatively the users' acceptance. The technical weaknesses which entail a rather limited life time and durability of fuel cells could have a negative impact on the users' acceptability of the FCEVs (Safarianova et al., 2011).

The main strengths of these vehicles are the social benefits, namely, the reduction of the CO_2 emissions, the increase in the air quality and the low noise levels for the vehicles equipped with an electric motor. Additionally, the fuel savings which occur while driving a PHEV, a BEV or a FCEV could offset their higher capital cost in the future; supportive schemes such as subsidisation and other soft policy measures including information campaigns could be beneficial for the acceptance of such vehicles.

14.5.2 Fuel perspective

Biodiesel and ethanol blends with diesel and gasoline up to 7% and 10% respectively can currently be used by the existing conventional vehicle technologies without the need for an engine modification and without voiding the vehicle warranty. Higher blend ratios cannot be currently used in the conventional technologies as engine modification is required. The users consequently if they want to use a "green" fuel should purchase a flexible fuel car which can use higher ethanol or biodiesel fuel mixtures.

Biofuels, and specifically LPG, as they are more adopted than other energy forms, do not face the infrastructure limitations like the FCs and EVs. This denotes that not only LPG is already accepted by the users but it can also prospectively be the chosen fuel for additional users. The market potential is, hence, high for this fuel. On the other hand, CNG and liquefied hydrogen would require high volume fuel tanks to meet the acceptable driving range for the user. This limitation of these fuels, in addition to the non-availability of refuelling stations, is expected to decrease the user acceptance for personal vehicles.

14.5.3 Refuelling and recharging infrastructure

At user level, the acceptability lies mainly on reliability of supply (similar to the social acceptability) and the costs of the infrastructural change (willingness-to-pay). The costs of infrastructural change include battery ownership or leasing costs and recharging rates for different locations according to energy providers.

One major benefit regarding the BEVs is the convenience they offer to the users with the home charging availability. Again, parallel policy schemes could be implemented for the promotion of the clean transport fuels for non capital expenditures, e.g. EV parking spots. Again, here one should mention the importance of information specifically on the advantages of clean transport fuels but also the cost-effectiveness in the long-run.

Finally, refuelling using biofuels is beneficial to the end-user as it does not imply any infrastructural change.

14.6 SWOT analysis of scenarios

14.6.1 Reference scenario

This scenario starts from the situation that policy makers, stakeholders and the public will only face incremental changes to the current situation. Powerful stakeholders like oil companies continue to focus on their core business (provide petrol and diesel gasoline) and will remain key players. The public continues to make use of conventional technologies and refuelling infrastructure, which is socially accepted. The efficiency of transportation vehicles will improve modestly and the diversification of the primary and final energy sources is limited. As internal combustion engines remain the dominant vehicle technology, the penetration of near-zero emission vehicles is limited.

Table 92: SWOT analysis: Reference scenario

SWOT analysis: Reference scenario		
	Strengths	Weaknesses
Internal dimension	Mature conventional technologies Fine-meshed refuelling infrastructure existing High social acceptance High user acceptance	Modest efficiency improvements in the future Limited diversification of energy sources 60% GHG emissions reduction not achievable Limited innovation and creation of green jobs

	Opportunities	Threats
External dimension	Potentially avoids technology lock-in Potentially avoids redundant investments or competing infrastructures (overcapacity)	Highly vulnerable to oil price shocks Build-up of GHG concentrations leading to high damage costs or adaptation costs Competitive advantage for non-EU countries

On the one hand, the continuation of the already existing policy measures results in only modest changes to the transportation system, and could potentially avoid technology dependence or lock-in and the potential development of expensive multi-fuel infrastructures for the transport sector. On the other hand, the continuation of being dependent on oil products makes this scenario highly vulnerable to oil price shocks or structurally increasing oil prices. No further strengthening of emissions or energy efficiency regulation will likely lead to an undesired build-up of GHG concentrations, which may lead to higher damage costs from climate change impacts or adaptation costs to avoid potential damages or disasters. Finally, the automotive industry in non-EU countries might obtain a competitive advantage over EU countries with respect to transport technology development and innovation, since they may promote early markets more aggressively.

14.6.2 Battery success

Battery electro-mobility seems to provide a number of benefits including the reduced dependency on oil resources. BEVs and PHEVs when driven in electric mode have zero CO_2 tailpipe emissions; thus increasing the air quality and meeting the aim of the White Paper as regards the ambitious emissions cut objective. In the first decade of the mass introduction of BEVs the purchase price is higher than conventional vehicles inducing that lower income groups may not have access to these vehicles. Regarding the technical limitations of BEVs, range limitations still exist; nonetheless they appear in long inter-urban highway trips. In this case where a breakthrough in battery technology is assumed, it is highly likely that new green jobs might be created. Environmental concerns about natural resources for producing batteries could be raised.

Table 93: SWOT analysis: Battery success

SWOT analysis: Battery success		
	Strengths	Weaknesses
Internal dimension	Vehicles with full electric range Diversification of energy sources Less vulnerable to oil price shocks 60% GHG emissions reduction achievable Less noise	Range limitations (battery weight, size, energy density) Higher incremental vehicles costs (user acceptability, social inequity) Investments in charging infrastructure (expensive transition phase) Chicken and egg problems
Exter	Opportunities	Threats

	Supports innovation and creation of green jobs Competitive advantage over non-EU countries/industries	Vulnerable to well-to-tank lack of decarbonisation: carbon intensity of grid electricity Environmental and political tensions with respect to battery material resources

14.6.3 Fuel Cell success

The breakthrough in the fuel cell technology development leads to a vast diffusion of FCEVs and thus implying a high reduction of the CO_2 emissions in the transport sector. Range limitations of the FCEVs might still exist; however the range provided by a FCEV is higher than a BEV and approximates than of a conventional ICE vehicle. The fact that the FCEVs are equipped with an electric motor implies that they do not make noise. As regards the FCEV purchase cost, during the first years of their introduction in the car market their cost may be significantly higher than the conventional gasoline and diesel vehicles and the lower income groups might not be able to purchase them. The fuel cell success case may support transport innovations in the EU and could create green jobs. Potential threats are the dependence on the carbon intensity of hydrogen production for reducing GHG emissions; however in the long-term, hydrogen production through electrolysis and use of nearly decarbonised electricity could eliminate the WTW carbon footprint of the hydrogen.

Table 94: SWOT analysis: Fuel Cell success

SWOT analysis: Fuel Cell success		
Internal dimension	Strengths	Weaknesses
	Vehicles with full electric range Diversification of energy sources Less vulnerable to oil price shocks 60% GHG emissions reduction achievable Less noise Less range limitations	Higher incremental vehicles costs (user acceptability, social inequity) Investments in refuelling infrastructure (expensive transition phase) Safety issues (public perception) Chicken and egg problems
External dimension	Opportunities	Threats
	Supports innovation and creation of green jobs Competitive advantage over non-EU countries/industries	Vulnerable to well-to-tank lack of decarbonisation: carbon intensity of hydrogen production

14.6.4 Dominant Biomass

Table 95: SWOT analysis: Dominant Biomass

SWOT analysis: Dominant Biomass		
Inter	Strengths	Weaknesses

	Rapid efficiency improvements ICE technologies (biofuels) Mature conventional technology Low costs on vehicle adaptation to biofuels Exploit existing liquid refuelling infrastructure Diversification of feedstock	Sustainable biofuel production Biofuel production costs Land use scarcity for 2nd generation biofuels Indirect effects of land use on food prices Some biomass/biofuels produce air pollution (NOx, SOx)
External dimension	Opportunities	Threats
	Exploit 3rd generation biofuels High potential for green jobs innovation	Limited land availability, competition for land use with other sectors No legislative framework for 3rd generation biofuels

The advantage of using biofuels is that their use requires limited changes to the existing vehicles and infrastructure; in other words the social and user acceptance might not be barriers to a wider biofuels entrance in the market. However, concerns about biofuel production costs, sustainable production and other potentially negative indirect effect might hamper achieving the full potential of this scenario.

14.6.5 "RENEW" battery success

This scenario employs the development and market penetration of multiple fuel, vehicle technologies and infrastructure. This provides a huge potential for the diversification of energy sources in favour of non-oil based fuels. This case could also be interpreted as a resilient strategy towards reducing GHG emissions and oil dependence, since multiple options are available and can compete for market share. However, there is a serious risk of getting ‘stuck in the middle’ since it will prove expensive to develop, exploit and maintain multiple vehicle-fuel combinations. This means that in such case the full potential of the fuels and technologies combinations might not be reached as in the dominant fuel paradigm cases discussed previously.

Table 96: SWOT analysis: "Renew" battery success

SWOT analysis: "Renew" battery success		
Internal dimension	Strengths	Weaknesses
	Risk hedging/distribution Technology independent context Diversification of energy sources Less vulnerable to exogenous factors	Slower technological improvements due to even distribution of R&D sources over multiple fuel systems Redundant investment in multiple infrastructures
Ex ter	Opportunities	Threats

	R&D opportunities in various clean technologies, green jobs Multiple pathways to achieve GHG emission reduction and less dependence on oil	Overcapacity due to multiple infrastructures ‘Stuck in the middle’: will any of the fuel systems reach their full potential? Mismatch between public funds and infrastructure maintenance

14.7 References SWOT analysis

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15 Conclusions

This study sought to verify the contributions of different fuel-technology combinations in achieving the reduction of emissions in the transport sector by 60%, while maintaining similar levels of activity in road transport (therefore excluding, by scenario definition, large scale modal shift towards non-road or non-engine transport modes).

To achieve this reduction objective, it is necessary to develop alternative vehicle technologies as well as the related infrastructure for alternative energy carriers. In the course of this study a number of scenario-cases with alternative fuel-technology combinations have been quantified with the PRIMES-TREMOVE transport model. Some of the central scenario cases assumed dominance of one technology over all others: battery electric vehicles, fuel cell electric vehicles, biomass fuel domination and a sensitivity scenario with GtL and BtL fuels; further scenarios with the co-existence of multiple technologies/fuels have also been quantified.

The study found that there is no single solution which can be used for all transport modes, as the only available energy carrier for this purpose, biofuels, cannot be produced to the amounts necessary in a sustainable manner. Biofuels should therefore be used selectively for transport modes where electric vehicles and fuel cells are not expected to be technically viable. For passenger cars and LDVs the development of battery electric and fuel cell vehicles should be pursued, keeping in mind the different upfront costs of the two technologies.

The possibility of large scale market penetration of both battery electric vehicles and fuel cell vehicles is highly dependent on the future developments of the basic technology they require, either the battery or the fuel cell. Literature sources claim that it is possible that these technologies will obtain sufficient development to start penetrating the market within the next 10 to 15 years exist for both technologies. If only one of the two technologies would reach the technology development necessary for penetrating the market of light-duty vehicles (i.e. covering all possible distance and weight segments of LDVs) contemporarily or slightly prior to large scale penetration the refuelling/recharging infrastructure would be built (necessary condition), then this technology would dominate the market and be able to substitute oil based fuels. If in addition the energy carrier is produced with low or free carbon sources then the developments comfortably lead to a 60% reduction in transportation emissions by 2050.

This reduction in emissions would be lead by LDVs, in particular by cars, and would be complemented by the use of biofuels in other transport modes, e.g. HDVs, aviation and navigation. In the case of successful development of both fuel cell vehicle technology and electric vehicle technology the following picture would be likely to emerge: fuel cells would dominate the LDV market for trips with mid to long distance, battery electric vehicles would co-exist mainly for LDVs mainly used for short to mid-range transportation; and plug-in hybrids. Biofuels would be used in all other transport modes, together with residual amounts of oil based fuels, where electric and fuel cell technologies are assumed not be able to penetrate due to range and technical limitations. It is clear that such a scenario requires the development of multiple infrastructure of full recharging infrastructure up to mid-range transport, full hydrogen refuelling infrastructure for mid and long-range trips, as well as infrastructure for biofuels for HDVs, ships and planes. Such development would incur in substantially higher costs for the transport sector. Further upfront costs (not quantified within this study) in particular for R&D would also be substantially higher.

The development of both technologies, battery and fuel cell, is highly dependent on R&D and infrastructure development expenditures, which rely at least to a certain extent on public resources and on public initiative. In the case of fuel cells the costs related to R&D are large and the expenditures needed to create at least a minimal structure for hydrogen refuelling infrastructure are very large. Technologies based on batteries also require R&D investment, but they can take benefits from recent developments in other industries (e.g. IT industry and mobile phones, etc.). For infrastructure of battery vehicles, the deployment of a slowly growing network of recharging points could occur smoothly and relatively cheaply due to the existence of the core infrastructure, i.e. the power grid. The costs for the entire development of the infrastructure for electric and fuel cell vehicles are different: the hydrogen infrastructure is generally more expensive (it requires both the development of pipelines and the development of refuelling points with pressurized tanks), although the amount of recharging points necessary for a full scale market penetration of electric vehicles is also considerable.

If neither of these two energy carriers would succeed in developing to the necessary extent to achieve large scale market penetration, the other option analysed in the course of this study are biofuels. Biofuels are present in all scenario-cases as a complementary fuel for passenger cars, and as a main solution for HDVs and non-road transportation. Although from a purely technical perspective biofuels could substitute oil based products entirely and substantial amounts of biofuels could be used as is demonstrated in the dominant biomass case, the availability of biofuels imposes serious limitations. In fact, assuming that the EU would produce to its full potential sustainable biofuels, this would not be sufficient for the entire transportation sector, and the remaining amounts would have to be imported. The effects of this additional demand for biofuels on the world markets are difficult to quantify, but would be expected to lead to increase in food supply costs (due to changes in land use), could lead to increased deforestation and thereby higher emissions caused by direct and indirect land use change. Furthermore the price of the biofuels themselves would rise considerably, thereby crowding out the use of biofuels in other world regions. It is therefore highly unlikely and questionable from a sustainability perspective if a shift towards biofuels in all transport modes is at all possible.

The limitations of the biomass supply imply that, as shown in the dominant biomass case, progress in technologies for electro-mobility needs to occur –either battery or fuel cells-, as alone conventional hybrids with biofuels would not be sufficient to obtain the 60% target. The progress necessary for electro-mobility technologies would not need to be to the extent of the dominant electro-mobility cases, but would still require substantial improvements from current levels. The issue of charging infrastructure would therefore also still be relevant. However the full coverage of the electric infrastructure would not be necessary, because, as seen in the dominant biomass case, a large part of the stock would be composed by plug-in hybrids. If fuel cell were used, a case not analysed within the context of this study, the infrastructure requirements may be different.

Under the circumstance of failure of electro-mobility either due to lack of infrastructure or of sufficient technological improvement and under the condition of abundance of natural gas worldwide, a further solution could be the use of GTL. GTL is a fully fungible fuel, with the current vehicle technology and infrastructure, but it does not allow significant changes in emissions and only a slight improvement in efficiency. In this context of the failure of electro-mobility, in order to nonetheless obtain the 60% emission reductions, there are two possibilities: either to increase the availability of biomass, or to reduce activity and induce modal shift. The increase of biomass availability beyond the dominant biomass case is highly uncertain due to the necessity of importing the additional biomass which may cause a number of sustainability issues. The way therefore to achieve the 60% emission reduction in transport without exceeding the biomass availability in the dominant biomass case and without the development of electro-mobility would require the introduction of command-and-control type of legislation to induce activity reduction besides modal shift. The negative effects of this legislation would be substantial on utility.

The role of gaseous fuels (particularly of methane and LPG) was also analysed within the course of this study.The methane is analysed as being initially mainly CNG, blended in future with methane from biomass. These fuels and their vehicle technology (ICE) are mature technologies, available today and therefore represent a solution to reduce emissions and improve air quality in the short to midterm. The larger market penetration of such fuels has been found heavily dependent on the availability of infrastructure, as well as on market acceptance. CNG and LPG have been found in the course of this study to offer the possibility of emission reductions in the midterm, up to 2030. Beyond 2030, these fuels do not further increase their shares as in a context of decarbonisation they cannot compete with technologies which allow to reduce substantially or eliminate tailpipe emissions. In the context of electro-mobility cases the share of LPG and CNG decreases beyond 2030, whereas in the biomass cases and in the GTL variants the share remains almost constant, as these technologies can compete with the other available technologies if natural gas is blended with biogas. The main advantage with these technologies and fuels is the maturity of the technology, but uncertainty remains regarding market acceptance and infrastructure development.

Policy instruments were also analysed in the course of the study. Particularly two specific transport policy options, CO_2 and energy efficiency standards were tested. Results showed that the choice between these two policy instruments is not technology neutral and that the policies should be applied differently depending on the long-term goal and technology developments. The policy strategy necessary is therefore complicated as it requires anticipation of possible technology developments. The instruments need to be flexible in order to take into account different possible developments. It was found that whereas CO_2 standards promote technologies with low or emission free energy carriers, energy efficiency standards promote higher resource efficiency. The two instruments do not always promote the same technologies and can even pose obstacles to some technologies. Furthermore, the policy instrument needs to achieve high emission reductions that go beyond the transport sector: in case of electro-mobility coordinated action is needed to ensure that the energy system is able to produce electricity or hydrogen in a carbon free manner, and in all cases to a lesser or greater extent the biomass supply industry needs to develop. The current biomass supply industry is almost inexistent compared to the levels required by any of the cases considered within this study; this would need to include the development of the feedstock supply (agriculture) but also the development of the conversion industry (e.g. large scale bio-refineries) and the supply logistics both from feedstock producer to conversion industry and from the conversion industry to the end user. Further policy instruments would need to be in place to ensure the deployment of the necessary infrastructure for refuelling or recharging. The policy instruments therefore have to be broad, flexible and have to anticipate technology development.

The change in average annual investment requirements in emission reduction scenarios relative to the Reference is substantial. However, the results show that the highest percentage change of expenditures for purchase of transport equipment takes place in the long term (after 2030), which is the period of full deployment of the new fuel technologies.

The yearly average expenditures for investment in the first decade of the projection period are similar between the scenarios because the available options are almost the same for all scenarios. The main differences become apparent in the last 20 years of the projection period when a variety of options become available and cause a differentiation of the costs.

By 2050, fuel expenses decline in all emissions reduction scenarios, firstly because of the use of more efficient technology/fuel and secondly because fossil fuel prices increase less than in the Reference scenario. The contribution of the fuel price decrease in total fuel payments decrease in the long-term as use of oil products declines substantially. In the emission reduction scenarios however capital costs increase considerably. According to model results the net effect of the emissions reduction effort on total transportation costs remains positive, which means that the additional capital cost dominates over reduced fuel costs.

The investment required for developing the necessary recharging infrastructure is estimated at 211 billion € in the battery success case and at 207 billion € in the Renew battery success case[76].

The structure of expenditures is changing in the emission reduction scenarios, with considerably higher average annual expenditures for purchasing transport equipment over the projection period being compensated to a certain extent by lower fuel costs. The cash flow requirements for car purchasing by households increase substantially more than for business as the electrification deploys at much larger extent in private road transport rather than in public and freight transport. Policy instruments and private sector actions will have to be in place to address this issue; an example is the case of leasing deals from manufacturers for the batteries. The issue of financing large scale infrastructure developments necessary for the successful deployment of new technologies such as battery electric or fuel cell vehicles is of different nature, since in these cases the distribution business usually operates under a regulated monopoly regime. However, policy issues arise because of the need to anticipate

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[76] The present value of the electric road infrastructure costs is derived using a discount rate of 4%.

market developments and regulate investment in infrastructure prior to the actual market development.

The key elements that determine the cost of the different cases analysed are the costs of the main vehicle technologies and the biofuel prices. If the key technologies were not to develop at the optimistic levels assumed in this project the cost of a shift in the transport sector would be much higher. The level of biofuel prices depend considerably on world developments as well as technology improvements for biofuel production; it has been assumed in the scenarios that the prices of biofuels increase throughout the projection period as the improvements in technological developments are assumed to be overweighed by the limitations of biomass availability.

The scenarios with the highest costs are the Renew cases which assume the development of multiple infrastructures, where none of the technologies fully exploits their learning potential and all options are available contemporaneously. The cheapest case is the dominant electricity with fuel cell case: this result is caused by the positive assumptions on the techno-economic development of the fuel cell. If the techno-economic developments of fuel cells had a different time profile, or the costs did not reach such low levels, the costs of the fuel cell cases would rise significantly. The biomass based cases are more expensive than the optimistic fuel cell scenarios, because although there is larger use of lower cost vehicle technologies, the battery costs are not assumed to develop very optimistically, therefore increasing the cost of the plug-in-hybrids; additionally the fuel consumption of the cases remains higher. The battery success cases are still more expensive than the biomass cases, because although immense progress is assumed in the development of batteries, the costs for battery electric vehicles are higher even though they are partially compensated by the reduced energy expenditures.

Primary energy consumption levels shift substantially between the reference scenario and the cases analysed, but also between the cases analysed; all cases see a strong reduction in crude oil consumption compared to the Reference scenario. Cases relying on electro-mobility see a strong increase in the consumption of the primary energy forms used to produce the electricity or the hydrogen and as well as a shift towards biomass, but to a much lower extent than the biomass cases. The renew cases see a strong shift towards biomass, and a lower shift towards primary energy forms used for electricity generation. The assumption for all scenarios is that the power generation sector decarbonises. The GtL scenarios see a reduction in domestic primary energy consumption, but an increase in the consumption of GTL, which was not available in other scenarios; this implies higher energy consumption overall.

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17 Appendix A: PRIMES-TREMOVE Transport Model description

The PRIMES-TREMOVE Transport Model projects the evolution of demand for passengers and freight transport by transport mode and transport mean, based on economic, utility and technology choices of transportation consumers, and projects the derived fuel consumption and emissions of pollutants. Operation costs, investment costs, emission costs, taxes and other public policies, utility and congestion influence the choice of transportation modes and means.

The mathematical structure of the PRIMES-TREMOVE is considerably enhanced. It is essentially a dynamic system of multi-agent choices under several constraints, which are not necessarily binding simultaneously. Part of the model (e.g. the utility nested tree) was built following the TREMOVE model. Other parts, as for example the component on fuel consumption, follow the COPERT model.

- Various policies and energy and environment related issues may be studied including:
- Pricing policies, e.g. subsidies and taxes
- Technology diffusion and infrastructure
- Development of new transport fuels (e.g. bio-fuels, hydrogen, electricity, etc.)
- Climate change policies (e.g. carbon tax, ETS)

The model can either be used as a stand-alone model or may be coupled with the rest of the PRIMES energy systems model. In the later case the integration with the PRIMES model enhances the dynamic character of the model, since the interaction of the different energy sectors is taken into account in an iterative way.

17.1 Model structure

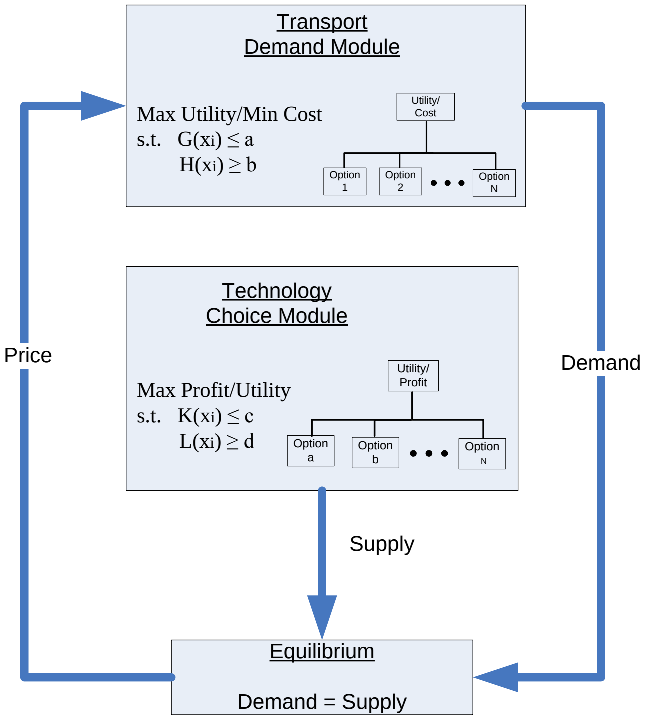
The model consists of two main modules, the transport demand allocation module and the technology choice and equipment operation module. The two modules interact with each other and are solved simultaneously.

The transport demand module simulates decisions regarding allocation of transport activity to the various modes, identifying transport service by mode of transport for both individuals and firms. The decision process is simulated as a utility maximisation problem with budget and other constraints in the case of the individual private passenger and as a cost minimisation problem in the case of firms.

The technology choice module determines the vehicle technologies (generally the transportation means) that will be used in order to satisfy each modal transport demand. It also enables the computation of energy consumption and emissions of pollutants from the use of the transportation means. The choice of technology is generally the result of a discrete choice problem in which consideration of cost is taken into account.

Both modules are dynamic over time, simulate capital turnover with possibility of premature replacement of equipment and keep track of equipment technology vintages.

The simulation of the transport market is formulated as a simplified Equilibrium Problem with Equilibrium Constraints (EPEC) transformed into a single Mixed Complementarity Problem (MCP). The transport demand module and the technology choice module are solved simultaneously in one single mathematical model, using the MCP algorithm PATH in GAMS. As the model is a single complementarity problem, it can handle overall constraints, for example to reflect environmental restrictions, the dual variable of which influence the endogenous choices of individuals and firms simulated by the model.



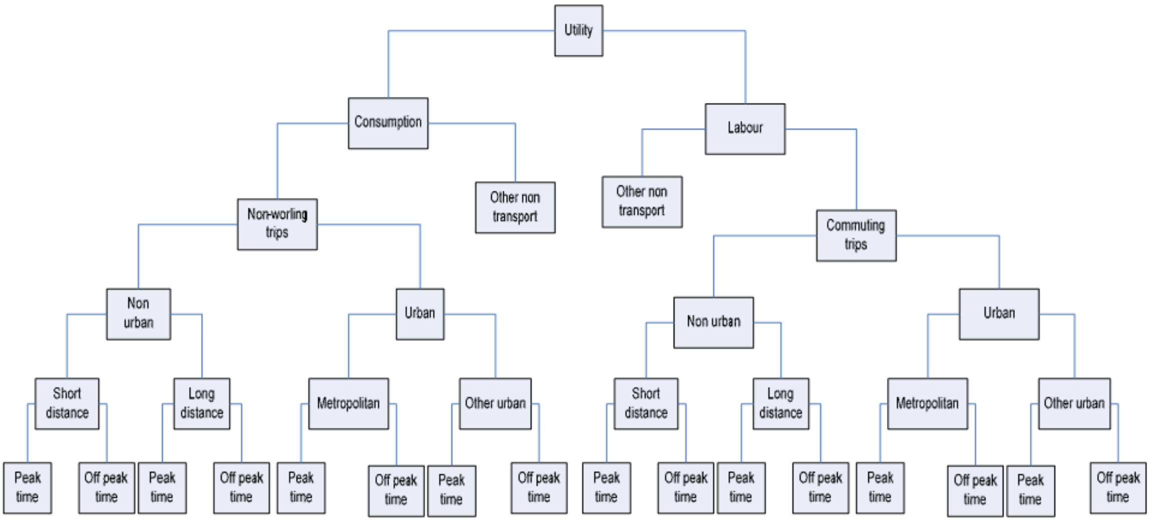
17.2 The transport demand module

The transport demand module simulates the decision process of the representative agent regarding the choice of transport activity. There is a distinction between private passenger transport and transport related to direct economic activity, such as transportation of commercial products and business trips. This distinction is triggered by the differences in the decision process between the individual passenger deciding on his/her own way of transport and the decision of a firm regarding budget allocation on logistics expenditures.

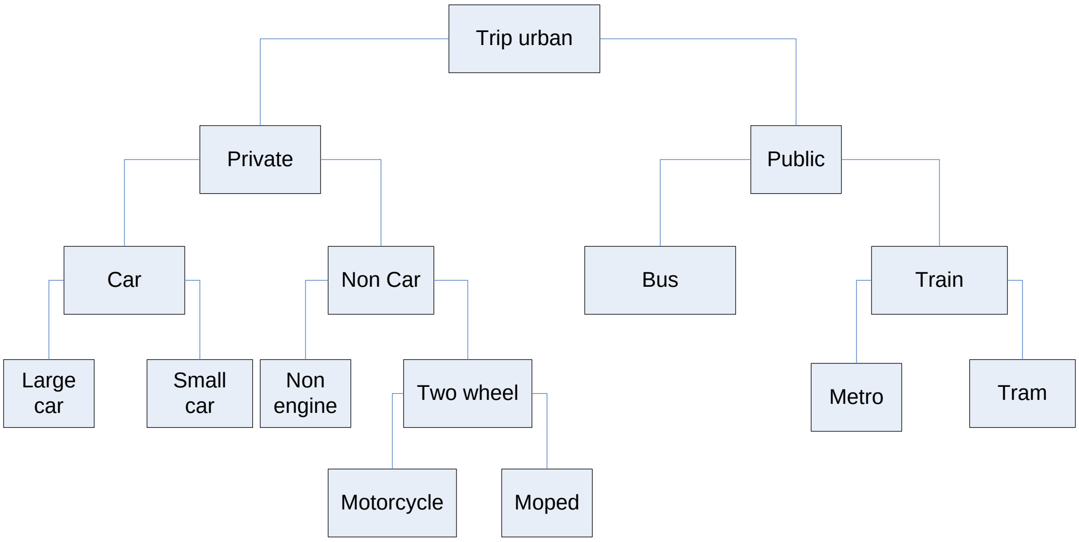
In passenger transport the representative individual, i.e. the passenger, is seeking to maximise a general utility function subject to a budget constraint that represents the total income. The cardinal expression of the individual’s utility is assumed to be determined by modal transport cost, an individual’s income and expenditure characteristics as well as historical behavioural features. The decision process of the private passenger is represented by a nested utility CES function, which involves also non transport spending.

This nested utility CES function which represents demand is articulated in the form of a utility tree. The top level of the tree is a node which denotes the overall utility. This node is then subdivided into other nodes which formulate the next (lower) level of the utility tree. All the nodes of the utility tree represent utility components which are defined through a function of the nodes of the lower level. The lowest level of the tree comprises of the elementary utility components which represent activity through different modes of transportation.

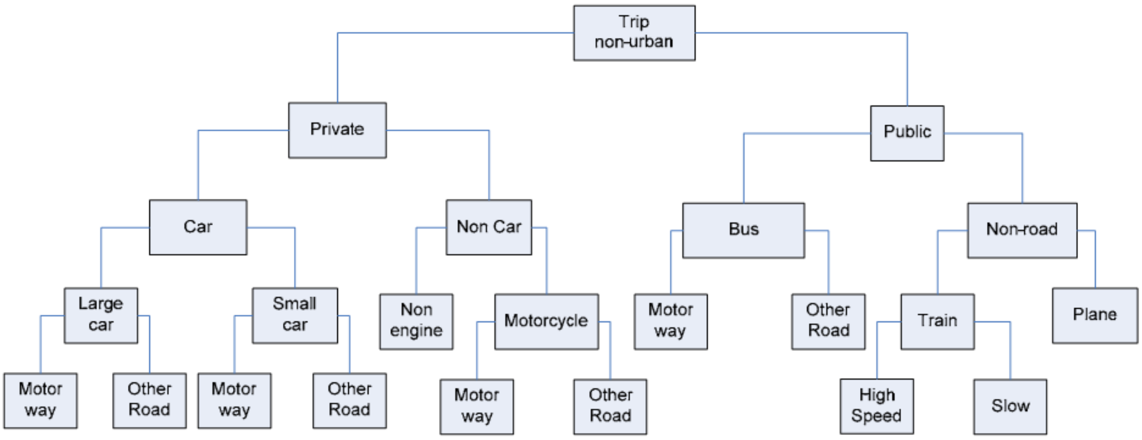
Initially the individual is deciding between the modal transport choices, i.e. whether to make a trip or not, the geographical and temporal identification of the trip etc. Each branch of the initial decision tree is further subdivided into several branches representing various modal choices. Two general decision processes of this type are identified depending on the geographical identity of the initial modal choice, namely urban and non-urban decision trees. The result of this secondary decision process is a more detailed modal identification of the agent’s decision up to the level of the choice of general vehicle (mean) category.



Private passenger primary decision tree

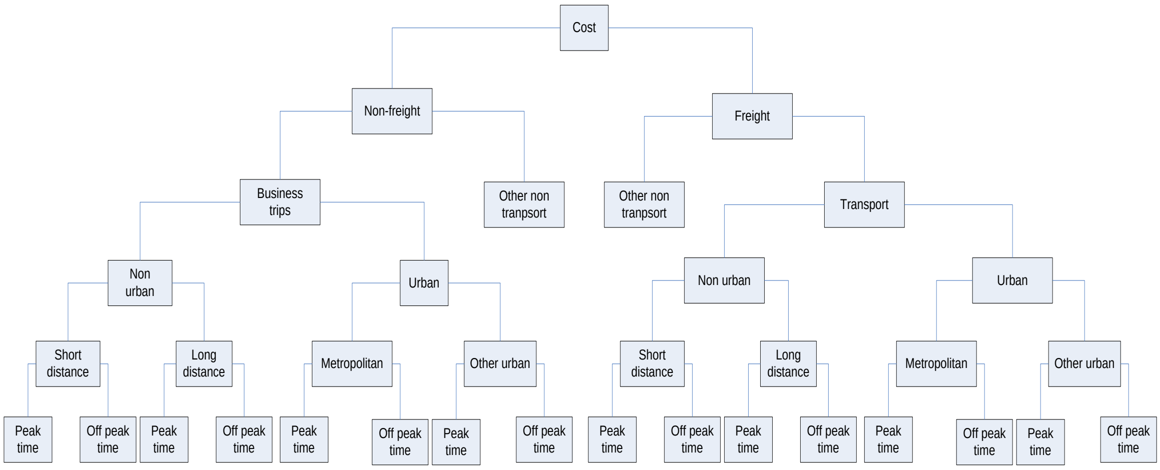


Private passenger secondary decision tree on urban transport

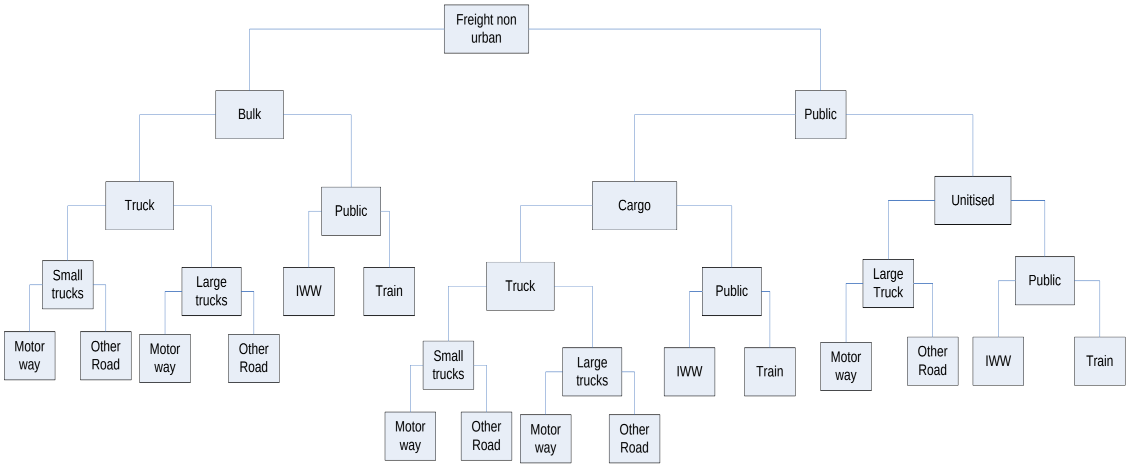


Private passenger secondary decision tree on non-urban transport

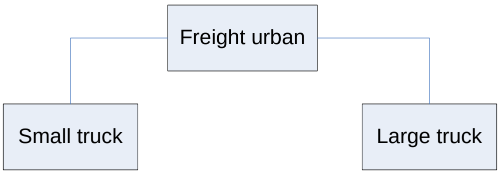
In a similar way the representative firm seeks to minimise total cost of satisfying its transport needs either regarding transportation of goods or business trips. The overall decision process of the firm is modelled as a nested CES cost function. The secondary decision process regarding the modal choice of business trips is similar to the decision process of the private passenger therefore they are not shown separately. As regards freight transport a representative secondary decision process is represented including all relevant modes of freight transportation.



Firm’s primary decision tree



Firm’s secondary decision tree on non-urban freight transport



Firm’s secondary decision tree on urban freight transport

17.3 Generalised Price of Transportation

The decision of each individual or firm depends on preference characteristics, described by the elasticities of the CES functions, as well as on the endogenously defined “*generalised price of transportation*”, which differs among the various modes of transportation.

In the case of private transportation, (i.e. personal cars and motorcycles for individual passenger and business trips as well as road vehicles for freight transport) the generalised price of transportation corresponds to total perceived costs of satisfying transportation demand at the level of each transport mode. These costs depend on actual cost of transportation as well as on the cost of time (travel time and congestion). Actual transport cost consists of:

- the capital cost of the vehicles, annualised by a subjective discount rate inclusive of risk premium
- fixed cost that includes annual maintenance, insurance, registration, etc.
- variable cost such as fuel expenses
- taxes and subsidies

Given that the endogenously defined vehicle stock satisfies the relevant modal transport demand (i.e. private cars satisfy all geographical and temporal modes of road transport) based on fixed annual utilisation indices, the aforementioned costs refer to the effective vehicle technology mix that serves each transport mode, which is endogenously determined by the model.

In the case of public transport (both for private passengers and for firms) the generalised price of transportation currently represents the sum of the average operational cost of the representative public transportation supplying firm and the cost of time. Average cost pricing of public transportation services is chosen because of the increasing returns to scale prevailing in this sector and because often public transportation forms incur budget deficits.

Average operational costs include the cost of the purchase and maintenance of the transport vehicle fleet, fuel cost, labour, taxation etc. Public transportation ticket prices are determined by using a Ramsey-Boiteux formulation which defines ticket prices by consumer type so as to recover total cost of the transportation service.

The technology choice model uses data reflecting the technical-economic characteristics of various vehicle technology and transportation means. The technology mix is endogenous to the model; hence the generalised price of transportation results from an interaction between the demand and the technology choice modules.

Cost of time is expressed as the product of travelling time (in hours/km) times the value of time (in €/km) and represents the value of travel time which differs between the individual passenger and the firm, and depends on temporally and geographically differences between transport modes. Travel time is directly influenced by traffic congestion and in the case of road transport a congestion function is used to calculate it. As for public transport, cost of time also includes waiting time which is determined too by a congestion function.

Travelling time for non-road transport is exogenously defined, taking into account average mileage and speed.

17.4 The technology choice module

The technology choice model defines the structure of the vehicle fleet that is optimum to deliver the transportation service as demanded for by the transport demand module. The technology mix and its operation is determined and so the model computes actual transport costs, energy consumption and pollutant emissions. The technology choice model is very detailed for road and rail transport, and less detailed for inland navigation and air transport.

17.4.1 Road transport

For road transport the actual vehicle stock is split into several vehicle types, and categories including passenger cars, motorcycles and mopeds, busses and coaches, light and heavy duty trucks. Different vehicle technologies and vintages depending on consumption, fuel type and emission standards are identified.

The calculation of the technology shares depends on total travel costs including purchase cost, fixed cost (maintenance, registration and insurance costs), fuel cost and time cost. The model includes all the technology classifications presented in Table 1 ranging from conventional ones complying with the EU emissions standards (EURO V, EURO VI) to alternative ones powered by compressed natural gas, biofuels, hydrogen and electricity. The shares of new conventional vehicle technologies have to comply with European emissions legislation which means that the new car registrations in 2010 for example, cannot comprise of EURO II gasoline cars.

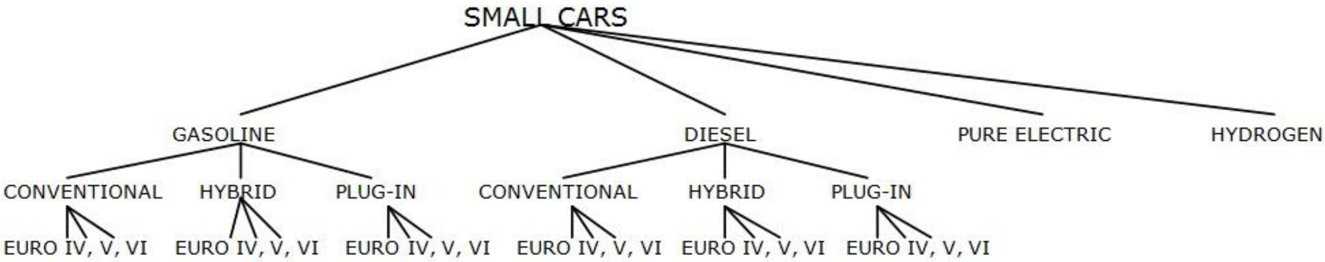
Vehicle technologies in the road transport sector using electricity as fuel have been fully incorporated into the Technology choice module. More specifically, as far as passenger cars and light duty vehicles are concerned, hybrid, plug in hybrid and pure electric powertrain technologies have been included into the choice Model.

Hybridisation of heavy duty trucks and urban busses has also been taken into consideration as an option for future freight and passengers transportation. The costs of new technologies are assumed to evolve dynamically, according to a learning curve which depends on cumulative production, reflecting economies associated with mass production. Such a learning curve is also assumed for batteries.

Decision making process is also influenced by the range provided by each vehicle technology and the availability of infrastructure; these features are particularly important when new fuels or new technologies enter the market.

Conventional technologies like ICEs do not have range limitations whereas battery and fuel cell electric vehicles do. This feature has been explicitly taken into account in the modelling approach of the choice of new vehicle technologies. The consumer upon the decision phase will certainly be in favour of vehicle technologies that will not pose range limitations. On the other hand, vehicles with limited range are endogenously penalised and the perceived costs to the consumer will increase due to loss of utility.

The choice of new vehicle technologies is based on the discrete choice theory and is modelled via decision trees. For each vehicle category (i.e. small, medium and big cars, light and heavy duty vehicles, busses, coaches and motorcycles) has been developed a decision tree. For illustrative reasons, the structure of the choice model for small cars is presented below:



In the above decision tree, consumer's behaviour is modelled as if choices between alternatives are made sequentially. For instance in the small car decision tree, the consumer is assumed to choose first between a diesel, a gasoline, an electric or hydrogen car. Once the consumer has made that choice, the next choice is between a conventional, a hybrid or a plug-in hybrid car. Thus, the latter choice is conditional upon the decision on the first node. Consumer's choice at each level is based on the concept of minimizing the aforementioned total transportation cost.

In general, the choice of new vehicle technologies is simulated using the following modified Weibull function:

$$sh_{j,t} = \frac{w_{j,t} * C_{j,t}{}^{-\gamma}}{\sum_j w_{j,t} * C_{j,t}{}^{-\gamma}}$$

where $sh_{j,t}$ refers to the share of the vehicle technology in a given year (i.e small car, gasoline, conventional EURO V or EURO IV), w is the "maturity factor" of the specific vehicle technology which is used to simulate technology availability as well as consumer preferences, γ denotes elasticity of substitution between the vehicle technologies and C is the annualised travelling cost attributable to each vehicle technology used.

Once the shares of the vehicle technologies are allocated, the shares of vehicle types need to be calculated (i.e. small car conventional gasoline versus small car hybrid gasoline). The shares are calculated according to the following function:

$$sh_{k,t} = \frac{w_{k,t} * IV_{k,t}{}^{-\gamma}}{\sum_k w_{k,t} * IV_{k,t}{}^{-\gamma}}$$

where $sh_{k,t}$ refers to the share of the vehicle type in a given year (i.e. small car, gasoline), w is the "maturity factor" of the specific vehicle type, γ is an elasticity of substitution between vehicle types and IV is calculated according to the mapping between each vehicle type shares and vehicle technologies as in the consumer's selection.

The calculation of IV is as follows:

$$IV_{k,t} = \sum_j C_{j,t} * sh_{j,t}$$

A vintage model with possibility premature scrapping has been formulated for vehicle turnover simulation. The model takes into account existing fleet structure and exogenously defined scrapping rates of vehicles based on calibrated Weibull distributions (for each country). The probability of a vehicle of type *k* with vintage *v* (year of first registration) to be in service in time $t > v$ (termed surviving probability $SP_{k,t}$) is given by the following modified, two parameter Weibull reliability function:

$$SP_{k,t}(t-v) = \exp\ -\left[\left(\frac{(t-v)+F(t-v)_k}{T_k}\right)^{b_k}\right]$$

$$with\ SP_{k,v} \equiv 1$$

where $t-v$ denotes the age of the vehicle $F_k(v-t)$ is the failure steepness for vehicles of type *k* and T_k is the characteristic lifetime of vehicle of type *k*. Parameters $F_k(t-v)$ and T_k are estimated based on available data on vehicle fleet characteristics. The choice about whether to satisfy activity with existing or with new vehicles is not exogenously predetermined but is endogenous depending on relative costs and utilities.

17.4.2 Rail transport

A similar discrete choice methodology is formulated for determining the structure of the train fleet, which distinguishes between metro, tram, urban and non-urban trains. Choice of new types of rail transport is simulated through a logistic share function that depends mainly on total operational costs, taken into account capital costs, fuel consumption, emissions etc. The pre-existing rail infrastructure is taken into account through an aggregate indicator and influences the degree of renewal of the train fleet.

17.4.3 Air Transport

For air transport, there exist three technologies indicating the potential technology progress of the sector. A conventional one baring current technological characteristics such as fuel consumption and emission factors, an improved and an advanced technology with better efficiencies and lower emission factors but with higher purchase costs.

In addition, as far as aircraft activity is concerned, it is discriminated into 5 distance classes depending on the trip length, according to TREMOVE database.

Airplane distance classes
< 500
500 - 1000
1000 - 1500
1500 - 2000
>2000

Each distance class is further disaggregated into the three aforementioned technologies.

17.5 Energy consumption and emissions

Consumption of transport fuels is endogenously determined by the model and is subject to environmental policy constraints. For road transport, fuel consumption and emissions of non-CO_2 pollutants are calculated by using the COPERT methodology. The computation covers a wide range of pollutants including NOx, CO, PM, CH_4, Non-Methane VOCs, N_2O, NH_3 and heavy metals.

The COPERT methodology enables calculation of fuel consumption of road vehicles as a function of their speed, which is determined by the endogenously calculated travelling time, the average mileage of trips per type of road transport mode, the occupancy factor for passenger trips and the load factor for freight transportations. The complete COPERT methodology has been integrated into the model providing a strong analytical tool for the calculation of the consumption of various fuels and consequent calculations of costs. For the technology choices not included in COPERT other data sources have been used such as results of the SAPIENTIA project. The calculation of fuel consumption for hybrid vehicles has been modelled in such a way that takes into account the region in which the vehicle is moving. For urban regions the fuel savings are significantly higher than in non urban ones because of the traffic congestion and the slower average speeds that lead to more braking and thus to more energy regenerated by the hybrid powertrain. As far as plug-in hybrid cars are concerned, they operate both as pure electric vehicles and as hybrids. The electric operation depends on the battery capacity which indicates an average all electric mileage between charges. When the battery supplies have been depleted, the vehicle switches to a hybrid mode burning conventional fuel. Pure electric vehicles have a single all electric operation and are equipped with high capacity batteries. Electricity consumption for plug-in hybrids and pure electric vehicles is being calculated using suggested efficiency figures from IEA and Argonne National Laboratory from the U.S. DOE. For rail, inland navigation and air transport, average mileage and specific fuel consumption factors are used for calculating fuel consumption and CO_2 emissions.

17.6 Time Horizon

PRIMES-TREMOVE Transport Model is a long-term model that is being set to compute projections for the period 2000-2050 for each EU-27 member state, running by period of 5 years. For years 2000 and 2005 the model results are calibrated to Eurostat statistics.

17.7 Source of Data

Historical data on vehicle stock for road and rail transport are taken from the TREMOVE database. Vehicle stock data for road transport are being updated in the framework of the FLEETS program and became available by the end of 2008. Data on vehicle costs, occupancy factors and average mileages are taken from the TREMOVE and SAPIENTIA databases. All other statistics are taken from EUROSTAT and DG TREN publications.

Classifications in the Transport model (road and rail)

Vehicle Category	Vehicle Type	Vehicle Technology
Small cars (<1.4 l)	Gasoline	Pre ECE, ECE, Conventional, Euro I-V
	Bio-ethanol	Bio-ethanol blend, E85 FFV
	Hybrid Gasoline	Euro IV-V
	Plug-in hybrid Gasoline	Plug-in hybrid technology
	Diesel	Euro IV-V
	Bio-diesel	Blended Bio-diesel
	Synthetic fuels	Synthetic fuels
	Hybrid Diesel	Euro IV-V
	Plug-in hybrid Diesel	Plug-in hybrid technology
	Pure electric	Pure electric technology
	Hydrogen	Hydrogen thermal, Hydrogen fuel cell
Medium Cars (1.4 - 2.0 l)	Gasoline	Pre ECE, ECE, Conventional, Euro I-V
	Bio-ethanol	Blended Bio-ethanol, E85 ethanol car
	Hybrid Gasoline	Euro III-V
	Plug-in hybrid Gasoline	Plug-in hybrid technology
	Diesel	Pre ECE, ECE, Conventional, Euro I-V
	Bio-diesel	Blended Bio-diesel
	Synthetic fuels	Synthetic fuels
	Hybrid Diesel	Euro III-V
	Plug-in hybrid Diesel	Plug-in hybrid technology
	Pure electric	Pure electric technology
	LPG	Conventional, Euro I-V
	CNG	Euro II-V
	Hydrogen	Hydrogen thermal, Hydrogen fuel cell
Big Cars (>2.0 l)	Gasoline	Pre ECE, ECE, Conventional, Euro I-V
	Bio-ethanol	Blended Bio-ethanol, E85 ethanol car
	Hybrid Gasoline	Euro III-V
	Plug-in hybrid Gasoline	Plug-in hybrid technology
	Diesel	Pre ECE, ECE, Conventional, Euro I-V
	Bio-diesel	Blended Bio-diesel
	Synthetic fuels	Synthetic fuels
	Hybrid Diesel	Euro III-V
	Plug-in hybrid Diesel	Plug-in hybrid technology
	Pure electric	Pure electric technology
	LPG	Conventional, Euro I-V
	CNG	Euro II-V
	Hydrogen	Hydrogen thermal, Hydrogen fuel cell
Motorcycles	2-stroke technology, Gasoline, biofuels	Conventional 4-stroke technology using gasoline/biofuels or electric motors
	Capacity 50-250 cc	
	Capacity 250-750 cc	
	Capacity 750cc	

<table>
<tr><th>Vehicle Category</th><th>Vehicle Type</th><th colspan="3">Vehicle Technology</th></tr>
<tr><td rowspan="2">Mopeds</td><td>Moped Conventional, Gasoline, biofuels</td><td colspan="3">Conventional, Euro I-V</td></tr>
<tr><td>Electric mopeds</td><td colspan="3">Pure electric technology</td></tr>
<tr><td rowspan="12">Light Duty Vehicles (<3.5 ton)</td><td>Gasoline</td><td colspan="3">Conventional, Euro I-V</td></tr>
<tr><td>Hybrid Gasoline</td><td colspan="3">LDV gasoline hybrid technology</td></tr>
<tr><td>Plug-in hybrid Gasoline</td><td colspan="3">Plug-in hybrid technology</td></tr>
<tr><td>Diesel</td><td colspan="3">Conventional, Euro I-V</td></tr>
<tr><td>Hybrid Diesel</td><td colspan="3">LDV diesel hybrid technology</td></tr>
<tr><td>Biofuels</td><td colspan="3">Biofuels</td></tr>
<tr><td>LPG</td><td colspan="3">LPG</td></tr>
<tr><td>CNG</td><td colspan="3">CNG</td></tr>
<tr><td>Synthetic fuels</td><td colspan="3">Synthetic fuels</td></tr>
<tr><td>Plug-in hybrid Diesel</td><td colspan="3">Plug-in hybrid technology</td></tr>
<tr><td>Pure electric</td><td colspan="3">Pure electric technology</td></tr>
<tr><td>Hydrogen</td><td colspan="3">Hydrogen fuel cell</td></tr>
<tr><td rowspan="8">Heavy Duty Trucks (> 3.5 ton)</td><td>Capacity 3.5-7.5 ton, Conventional</td><td rowspan="4">Diesel trucks</td><td rowspan="4">Methane trucks</td><td rowspan="4">LPG trucks</td></tr>
<tr><td>Capacity 7.5-16 ton, Conventional</td></tr>
<tr><td>Capacity 16-32 ton, Conventional</td></tr>
<tr><td>Capacity >32 ton, Conventional</td></tr>
<tr><td>Capacity 3.5-7.5 ton, Hybrid</td><td colspan="3" rowspan="2">Truck diesel hybrid technology , biofuels, synthetic fuels</td></tr>
<tr><td>Capacity 7.5-16 ton, Hybrid</td></tr>
<tr><td>Capacity 16-32 ton, Hybrid</td><td colspan="3" rowspan="2">Electric trucks, Hydrogen fuel cell trucks</td></tr>
<tr><td>Capacity >32 ton, Hybrid</td></tr>
<tr><td rowspan="8">Busses-Coaches</td><td>Diesel</td><td colspan="3">Conventional, Euro I-V</td></tr>
<tr><td>CNG</td><td colspan="3">CNG thermal</td></tr>
<tr><td>LPG</td><td colspan="3">LPG</td></tr>
<tr><td>Busses only Hybrid Diesel</td><td colspan="3">Hybrid Diesel technology</td></tr>
<tr><td>Pure electric</td><td colspan="3">Pure electric technology</td></tr>
<tr><td>Biodiesel</td><td colspan="3">Biodiesel technology</td></tr>
<tr><td>Synthetic fuels</td><td colspan="3">Synthetic fuels</td></tr>
<tr><td>Hydrogen</td><td colspan="3">Hydrogen fuel cell</td></tr>
</table>

According to FLEETS database there were no small diesel car reported till 2005 so they will be taken into consideration in the Technology choice model beyond 2010. The same goes for small diesel hybrid cars.

Passenger cars burning CNG and LPG are considered to be either Big or Medium but not Small ones.

Heavy duty trucks are supposed to be powered by diesel. In cases in which gasoline trucks occurred in national fleet statistics, they were assumed to be light duty vehicles.

Busses are considered to operate in urban environment whereas coaches in inter- urban.

Vehicle Category	Vehicle Type	Vehicle Technology
Metro	Metro Type	Metro Technology
Tram	Tram Type	Tram Technology
Passenger Train	Locomotive	Locomotive diesel
		Locomotive electric
	Railcar	Railcar diesel
		Railcar electric
	High speed train type	High speed train technology
Freight Train	Locomotive	Locomotive diesel
		Locomotive electric
	Railcar	Railcar diesel
		Railcar electric

Vehicle Category	Vehicle Type	Vehicle Technology
Aviation	Distance travelled -500 km	Conventional, improved, advanced /kerosene, biofuels
	Distance travelled 500-1000 km	Conventional, improved, advanced /kerosene, biofuels
	Distance travelled 1000-1500 km	Conventional, improved, advanced /kerosene, biofuels
	Distance travelled 1500-2000 km	Conventional, improved, advanced /kerosene, biofuels
	Distance travelled 2000- km	Conventional, improved, advanced /kerosene, biofuels

Energy Carriers for Transport		
Gasoline	Diesel	LPG
CNG	Bio-ethanol	Bio-diesel (RME, Fischer Tropsch,etc)
Hydrogen	Electricity	Synthetic fuels

17.8 Electricity infrastructure costs calculation

Electricity infrastructure costs are estimated based on ex-post calculations. Taking into account that a large part of the necessary infrastructure of electric vehicles already exists (i.e. electricity grid), the infrastructure costs are based on the number of charging stations needed to be developed. There has been assumed different electricity recharging infrastructure development for lighter electric vehicles (e.g. cars, LDVs and 2wheelers), heavier electric vehicles such as HDVs and coaches and dedicated urban battery swapping stations for electric buses.

Table 97: Overview of possible costs of recharging points

Source	Year	Type of installation	Original currency		Comments	Cost in Euro
Future Transport Fuels Report	2010	per slow charging point				3000
Coulomb technology[77] homes, businesses and public locations		per charging point	$	8043	Total endeavour US$37000000; for 4600 charging points	6540
GM[78]		installation costs	$	1500		1220
BBC[79]	April 2009	fast charging point	£	2000		2960
Green Car guide[80]	2007/2008	charging posts	£	3300		4884
		charging posts	£	6379	185,000 in funding for 29 charging points in London	9441
City of Westminster[81]	2006	SGTE Power France	£	1000	4 vehicles	1480
		DBT France	£	2500	4 vehicles	3700
			£	1500	1 vehicle	2220
			£	1500	1 or 2 vehicles	2220
		Transtex International France	£	1500	2 vehicles	2220
		Elektromotive UK	£	4500	1 vehicle	6660
		Ciant	£	2500	2 vehicles	3700
		Spie-Trindel France	£	1500	up to 10 vehicles per bay	2220
Plug in Points[82]		target	£	500		740

It has been assumed that for light electric vehicles such as cars, LDVs and 2wheelers there will be a dedicated slow charging point (e.g. private for each household) mainly for slow overnight charging; these slow residential charging points are operating on low voltage (220V) and charging time ranges between 4-7 hours depending on the battery capacity of the electric vehicle. Slow public charging points are assumed to be available in public areas such as parking lots; commuters will be able to park their car and recharge it throughout the day. Slow public charging points could also be available in other urban areas other than parking lots. Fast charging points are assumed to develop over time but at a slower rate compared to slow

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[77] http://gigaom.com/cleantech/coulomb-to-deploy-4600-electric-car-charge-spots-thanks-to-doe/

[78] http://gigaom.com/cleantech/coulomb-to-deploy-4600-electric-car-charge-spots-thanks-to-doe/

[79] http://news.bbc.co.uk/2/hi/business/8002184.stm

[80] http://www.green-car-guide.com/articles/westminster-council-launches-uks-largest-on-street-electric-car-charging-service.html

[81] It is assumed that all the charging points mentioned are slow charging points

[82] http://pluginpoints.com/Approach.htm

charging points. A fast charging station is designed to charge a multiple number of EVs simultaneously in a way the current refuelling stations operate.

In the ex-post calculations, it was assumed that the cost per private slow charging point declines from approx. 1000€ currently to 200€ by 2050.For slow public charge points, the cost per point is assumed to drop from 4000€ currently to 400€ by 2050. Companies like SGTE Power and DBT have already installed in Paris slow charging points for electric vehicles. In UK there are approx. 200 charging stations; the vast majority installed by Elektromotive. Table 97 provides details regarding costs and technical specifications of recharging stations as they have been found in a variety of sources, including internet sources.

As far as fast charging points are concerned, their costs decrease from 10000€ currently to 2000€ by 2050. It has been assumed that for large and heavy electric vehicles such as HDVs and coaches there will be dedicated electricity recharging infrastructure. The costs of the recharging stations for heavy electric vehicles are assumed to be higher than for lighter vehicles; the number of electric trucks and coaches though is limited and the additional infrastructure costs are lower than for lighter electric vehicles.

18 Appendix B: PRIMES and PRIMES-Biomass Models brief description

18.1 PRIMES Model

The energy model PRIMES simulates the European energy system and markets on a country-by-country basis and provides detailed results about energy balances, CO_2 emissions, investment, energy technology penetration, prices and costs for 5-years intervals over a time period from 2000 to 2050. The model produces future projections of a detailed inventory of energy and process related CO_2 emissions and associates this projection with drivers such as energy prices, economic activity, technological changes and a series of policy instruments. The model establishes a complete linkage between supply and demand for energy with endogenous price formation. Bottom-up and engineering oriented information about alternative policy options is also included at a sufficient level of detail. The model is designed to handle renewable, efficiency and climate change targets, with representation of various possible policy instruments. The representation of sectors, countries and technologies is comprehensive and suitable to assess alternative target schemes which can be specified at different levels: at the overall EU level or at the level of each member state (with differentiation) and/or at the level of specific sectors of activity. PRIMES is organised in sectoral sub-model, among which the power generation and steam/heat sub-model is the largest and most detailed. The demand sectors are represented by sub-models, one per sector. PRIMES include also sub-models for gas supply and transport (detailed Eurasian coverage), biomass supply and conversion, hydrogen production and transportation, refineries, solid fuel processing and fossil fuel extraction. The output of PRIMES is a complete projection of energy balances, details of energy supply and demand by sector, costs, investments and emissions.

See www.e3mlab.ntua.gr for further details.

18.2 PRIMES-BIOMASS supply Model

PRIMES Biomass Model is currently operational and is linked with the PRIMES large scale energy model and can be solved either as a satellite model through a closed-loop process or as a stand-alone model. It is an economic supply model that computes the optimal use of biomass resources and investments in secondary and final transformation, so as to meet a given demand of final biomass energy products, projected to the future by the rest of the PRIMES model. Like PRIMES, it covers all the EU countries, it performs dynamic projections to the future from 2000 until 2050 in 5-year time period step, it is calibrated to base years 2000 and 2005 and partially to 2010 so as to reproduce Eurostat statistics, computes endogenously the energy and resource balances to meet a given demand by PRIMES model, calculates investments for technologies, costs and prices of the energy forms and the emission of pollutants.

Moreover the PRIMES biomass supply model determines the consumer prices of the final biomass products used for energy purposes and also the consumption of other energy products in the production, transportation and processing of the biomass products. Prices and energy consumption are conveyed to the rest of the PRIMES model. A closed-loop is therefore established. Upon convergence, a complete energy and biomass scenario can be constructed.

Table: Primary, Secondary & Final Commodities

PRIMARY COMMODITIES	**SECONDARY COMODITIES**	**FINAL COMMODITIES**
Starch biomass Sugar biomass Oil Biomass Wood lignocellulosic biomass Wood biomass from forestry Biomass from agricultural residues Industrial solid biomass Sewage sludge Municipal solid biomass Landfill gas Manure Organic biomass from animals Algae oil	Starch biomass pretreated Sugar biomass pretreated Pure Vegetable Oil pretreated Agricultural residues pretreated Wood biomass pretreated Wood logs for small and large scale combustion Pellets for small & large scale combustion Animal waste Black liquor Sewage sludge conditioned Dry Manure In situ gas Algae oil pretreated	Bioethanol: Bioethanol from Sugars, Bioethanol from Starch, Bioethanol from lignocellulosic Biodiesel: Biodiesel from transesterification, Fischer Tropsch Biodiesel, Pyrolysis Biodiesel, Hydro Thermal Upgrading Biodiesel Biogas (Biomethane): Biogas from anaerobic digestion & Synthetic Natural Gas Biokerosene: Fischer Tropsch Biokerosene & Biokerosene from algae oil transesterification Small Scale Solid Large Scale Solid Bioheavy: Pyrolysis Oil, Bio-crude, Vegetable Oil (pure or recovered) pretreated Biohydrogen Waste Gas: Landfill Gas & Sewage Sludge Gas Waste Solid Mass burn waste & Refuse derived fuel

19 Appendix C: Literature review[83]

This section summarises a literature review conducted within this project. More details can be found in a separate document delivered to the Commission.

Within the scope of this review twenty six studies have been reviewed. The synthesis focuses on the decarbonisation of transport. The review identifies several types of measures, such as transport efficiency improvements and transport volume management that play an important role toward decarbonisation. However, it was clear from the review that alternative fuels are likely to be the ultimate solution to decarbonise transport, by gradually substituting the fossil energy sources, which are responsible for the CO_2 emissions of transport (FTF, ROUTES). The review of the studies focused on comparing the main assumptions of the scenarios included in the studies and on categorising the study outcomes conceiving recommendation about policy measures.

The studies were categorised according to the following criteria:

- Timeframe of the scenarios
- Regional scope of the analysis
- Sectoral coverage
- Whether the scenarios and consequently the study refer only to transportation or to the overall economic system
- Whether soft or hard measures are proposed to achieve targets
- Whether the measures proposed are technical or non-technical
- Whether the study considers life cycle considerations (WTW, TTW, and WTT).

19.1 Analysis results for each transport mode

In the following sections we present the main analysis results and concluding remarks related to the transport modes considered in the studies and the potentiality of using fuels other than the ones used today toward the decarbonisation of the sector.

It is a common feeling that transport dependence on oil needs to be differentiated. As an example, air transport sector is the one which is most dependent on oil; more than 99.9% of jet fuel is petroleum-based (IATA). For road and marine applications many possible alternatives exist, such as other fossil resources, biomass, renewable energies and nuclear power (via electricity and hydrogen production); at present, the majority of fuels are petroleum-based as well. The alternative fuels could all be used in the form of different types of fuel for different types of vehicles, including those powered by the most common internal combustion engines, by hybrid propulsion in a combination of internal combustion engines and electric motors, fuel cells combined with an electric motor and battery supplied electric vehicles (FTF).

According to (FTF) the main options of alternative fuels for oil substitution are the following:

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[83] Section prepared by Exergia

- electricity, via battery or hydrogen/fuel cells
- liquid biofuels, in different forms
- methane (natural gas of fossil origin or biomethane produced from biomass), in compressed gaseous form or in liquefied form as LNG
- synthetic fuels, bridging the gap from fossil (coal, natural gas) to renewables (biomass)
- LPG

Electricity and hydrogen are universal energy carriers and can be produced from a wide range of primary energy resources.

All these alternative fuel options can be produced from low- CO_2, and finally from CO_2 -free sources. Substitution of oil in transport by these main alternative fuels leads then inherently to a decarbonisation of transport if the rest of the energy system is decarbonised.

Almost all studies seem to agree that the near-term prospects (next 3-6 years) for alternative fuels or utilization of breakthrough technologies are limited and that more opportunities may be available in the medium or longer term. Some of the alternative fuels, as for example the fuels based on biomass-to-liquids and coal-biomass-to-liquids, and hydrotreated fuels from renewable oil sources could under certain conditions reduce the impact on GHG emissions (FTF). The production potential and cost of these fuels depends on sustainable, low-cost feedstock, the impacts on land use and on competition with other potential uses. Alternative fuels which are energy carriers, such as electricity and hydrogen, will have provide benefits in terms on GHG emission reduction if their production is sufficiently decarbonised.

The reviewed literature is positive that under certain conditions transportation can evolve towards decarbonisation provided that substantial additional investment develops on a world-wide basis. Another clear conclusion that has to be stressed at this point is that the benefits of using alternative resources for transportation should be considered in light of potential benefits of use in other parts of the energy sector (ETP10, FTF) and, indeed, few of the studies considered any co-impacts. Power and transport sectors are closely related, but can be decoupled, and require different technical approaches. Decarbonisation of transport and decarbonisation of the energy system can therefore be considered as two complementary strategic lines (ETP10).

Not all alternative fuels are equally suited for all modes of transport, and also not for all sectors within a specific mode. The requirements of the different modes and the possibilities of the different fuels therefore need to be analysed for each mode separately.

The suitability of a fuel for a specific transport mode will depend on a number of factors such as market maturity, safety, vehicle compatibility, energy density.

19.1.1 Passenger vehicles

Light-duty vehicles (LDVs) accounted for about 45% of global transport energy use in 2007 (ETP10). **Electric vehicles** are suggested as the preferred solution towards decarbonisation of transport sector.

The reviewed studies identify significant impact on the power sector from wide diffusion of grid-charging, battery-based electric vehicles. The impacts studied regard the additional demand for electricity, the effects on the marginal dispatched plants for meeting the demand for electricity by electric vehicles, the implications for the load patterns depending on various charging incentives, and the possible two-ways interaction between the electricity market and the use of batteries either as load or as storage. Selected relevant studies are the following: TROAD, RD09JRC, MAR09JRC, TRANSF08, MOB04, TEC09. The analysis of implications on GHG emissions depend on the future structure of the power sector and the possible development of decarbonisation policies in this sector.

The literature reveals that there is an ongoing debate about whether **hydrogen fuelled cars** and battery-based electric vehicles constitute the optimal solution for future decarbonisation in road transport. Alternative scenarios have been quantified for that purpose, exploring electrification as the main low carbon option for the future or alternatively hydrogen as a dominant energy carrier (WEC2007, ETP10, MOB04, WETO H2). Some studies, mainly from IEA, anticipate that both options will make their contributions.

The main challenges and uncertainties for the introduction of battery-electric (EV) and plug-in hybrid vehicles (PHEV), as mentioned by the studies, include the following:

- Requirements for a new charging infrastructure, especially difficult to develop in densely populated urban areas.
- Standardization of charging infrastructure, plugs and grid-vehicle communication
- High initial costs of battery-electric vehicles, combined with uncertainties associated with battery lifetime
- Limited driving range combined with long recharging time
- Uncertainties regarding technology robustness of electric and plug-in hybrid vehicles
- Battery lifetime, to be proven in large scale field trials and battery safety issues
- Impact of fast charging on battery lifetime and energy efficiency
- Impact on battery lifetime of using electric vehicle batteries for vehicle-to-grid services
- Development of battery costs
- Material availability issues for batteries (rare earths)
- Development of future vehicle and energy tax regimes and regulations.

According to the BLUE Map scenario (IEA) PHEVs and EVs are expected to begin to penetrate the market soon after 2010, with EVs reaching sales of 2.5 million vehicles per year by 2020 and PHEVs reaching sales of nearly 5 million by 2020. By 2030, sales of EVs are projected to reach 9 million and PHEVs are projected to reach almost 25 million. The ultimate target is to achieve 50 million sales of both types of vehicles annually by 2050.

On the other hand, MAR09JRC assumes that the EVs shares in total car sales will remain limited until 2020 (0.5% to 3%) but may rise up to 30% until 2030.

DET06 assumes that gasoline and diesel hybrids are expected to achieve a combined maximum market share of 25% by 2030. ERTRAC09 specifies that in 2030, plug-in hybrid and fully-electric vehicles will be a growing segment of the light-duty fleet, especially in urban environments with their share in new sold vehicles rising up to 15%.

For road transportation, neat synthetic or paraffinic fuels could also be used, as well as methane or LPG. Possible risks and adverse effects from market fragmentation and resulting limitations in economies of scale in case of competition between fuels need to be further clarified.

19.1.2 Rail

Among the studies reviewed, there was no study dedicated to rail transportation. A few specific references exist in some studies (TEC09, FREI09, FTF). A clear trend, though, is that freight transport by rail is expected to increase substantially.

Railways are already largely running on alternative fuels, as railway tracks are already electrified to about 50% of their total length in the EU (FTF). Urban rail systems are nearly 100 % electrified.

Non-electric railways run on diesel; several options are available to substitute the diesel in locomotives including biofuels, LNG or even hydrogen, which would allow a decarbonisation of railways where electrification is difficult or not economic.

Apart from a few large countries worldwide (Russia, U.S., China) that move raw materials over long distances, rail accounts for a relatively small share of freight transportation compared to trucks, in most EU countries. What is clear from the studies is that although rail transport is more fuel efficient than road transport, rail’s share of the freight market in most countries has been contracting.

It is likely that a combination of fiscal, infrastructural and regulatory policies will be needed to reverse the decline in rail’s share in the freight market.

19.1.3 Aviation

Air transport has grown faster than any other transport mode in recent years and is likely to continue growing rapidly in the future (IATA). The efficiency of air transport has been improving steadily over time as airlines respond to high fuel costs, but at a much slower pace than travel growth. Thus, aircraft CO_2 emissions and dependence on oil have been rising rapidly.

Currently, the dominant propulsion technology in commercial air transportation is gas turbine fuelled by kerosene using mature technologies. The air transport industry has made impressive improvements in aircraft energy efficiency over the years, but these were mainly limited to incremental steps within the same technology paradigm. The improvement was also a result of operational measures like air traffic management or ground traffic management at airports. Despite these developments, the growth of global air traffic has led to immense substantial increase in oil consumption and greenhouse gas emissions caused by air transport.

The studies focusing on aviation (IATA, RAND, E4tech, WEC2007, TEC09) show that CO_2 reduction in a range of 70% to 80% is possible. This reduction is expected to be achieved using biofuels and highly efficient technology.

Biofuels are widely investigated as alternative fuels for aviation. The limitations are considerable and concern operational and safety requirements of aviation, in addition to general restrictions, such as resource availability, sustainable production or energy efficiency. An important requirement by aviation is that the fuel still must be perfectly liquid at low temperatures in great heights. Recent studies and experiment seem to conclude that there would not be serious problems of using biofuels as admixtures to fossil kerosene, up to a certain rather moderate blending proportion.

In 2009, synthetic paraffinic kerosene produced from the Fisher Tropsch process (FT-SPK) with coal (CTL), natural gas (GTL) or biomass (BTL) has been approved for use in civil applications for blending ratio up to 50% with conventional jet fuel. BTL is close to the demonstration level. The use of fully synthetic kerosene is foreseen as a future objective.

Other alternative fuels may appear for aviation in the future, but in order to have any significant impact by 2050, they will need to be "drop-in", i.e. compatible with existing engines, airframes and fuel supply systems and infrastructures.

In the longer term, hydrogen or other "non drop-in" alternatives could offer a potential if they succeed in demonstrating a significant environmental and economical advantage that overcome the cost required to adapt aircraft and infrastructures.

Some measures, such as reducing overall airplane travel volumes, may reduce emissions and consumption across the board. Other measures, such as improving aircraft engine efficiencies, may result in trade-offs between different pollutants, for example achieving a reduction in CO_2 emissions at the cost of higher NOx emissions.

Assertion of additional analysis work is mentioned to be required to better understand the potential and cost of reducing CO_2 emissions from the aviation sector in general (RAND, IATA, TEC09).

19.1.4 Maritime transport

International maritime activity has grown significantly in recent years, doubling between 1985 and 2007 (TEC09). International sea transportation relies mainly on heavy fuel oil (FTF). According to IEA data, international maritime activity accounted for 543.4 Mt of CO_2 emissions from fuel combustion in 2005.

Maritime transport could substitute conventional fuels by being supplied with synthetic fuels, hydrogen (ongoing research), methane, LPG and LNG. The 2008 amendments to Annex VI of the International Convention for the Prevention of Pollution from Ships laid down significantly more stringent sulphur content limits in marine fuels internationally. The requirements of Annex VI drove an increased interest in LNG as a fuel especially for those ships carrying cargo across short distances. LNG, indeed, remains a viable alternative for maritime transport; however, there is much to be done in terms of infrastructure and bunkering support.

The main conclusions of the studies focusing on maritime transport are summarised as follows:

- Shifting to alternative fuels may be relatively expensive for ships

- Low GHG biofuels could cut maritime transport CO_2 emissions substantially
- There exist a significant untapped potential of energy efficiency improvement
- Decarbonisation of maritime sector will be likely achieved only through the implementation of international policies to encourage reductions of CO_2 in fuel use.

19.2 Economic considerations

19.2.1 Electricity

Costs of Li-ion batteries currently on the market are between 1000 and 2000 €/kWh according to MCK09, RETRANS and RD09JRC. MCK09 states that cost reductions between 5 and 8 percent per year would be possible up to 2030. The IEA estimates that US$300-600/kWh could be an achievable target for battery costs by 2015 (IEA09). Various sources even claim that cost reductions to 200 - 300 €/kWh are possible in the longer term future. This would reduce the battery costs from typically €20,000 - €40,000 per vehicle to €4,000 - €6000 per vehicle.

MCK09 estimates the additional costs of a plug-in hybrid compared to a conventional car to be € 16.000 in 2006, and projects that these costs could fall to € 3.500 by 2030. This is for a vehicle with 60 km electric range and a battery capacity of 14 kWh. Other studies mention additional costs of £6,500 for a plug-in with 35 km electric range and £20,000 for a vehicle with 350 km electric range.

Based on RD09JRC it is expected that Li-ion battery cost would fall as low as 395 $/kWh and 260 $/kWh for a PHEV10 and a PHEV40 respectively with 100000 units produced. The battery cost goal set by the USABC range from 300 $/kWh to $200/kWh for the PHEV10 and PHEV40 respectively. The MIT estimates that the commercialization of a PHEV30 requires a cost as low as 320 $/kWh. Some researchers believe that PHEVs would become cost efficient to consumers if battery prices would decrease from 1300 $/kWh to about 500 $/kWh.

According to IEA's scenarios (Baseline, BLUE Map), total additional investment costs for vehicles in the BLUE Map scenario to 2050, relative to the Baseline, amount to about $22 trillion. This is about 10% higher than the levels of investment in the Baseline scenario of around $231 trillion and reflects significant cost reductions over time (LDVs alone account for around 60% ($139 trillion) of total transport investments). At a 2050 oil price of $120/bbl, fuel savings in the BLUE Map scenario reduce costs by around $20 trillion, nearly offsetting the higher vehicle costs. At $70 per barrel of oil in 2050, fuel costs are reduced by $47 trillion. In that case, the total vehicle and fuel costs are around $25 trillion less than those in the Baseline scenario. With a 10% discount rate, the vehicle and fuel costs in the Baseline drop to roughly $95 trillion, with the costs in BLUE Map being about $1 trillion higher.

In some transport sectors, electrification is not likely to be possible due to driving range, weight limitations or payload requirements. As for shipping, using biofuels is a suitable option for freight road transport.

19.2.2 Biofuels

At present, the cost of biofuels is significantly higher than oil product prices. According to analysis by IEA the cost of biofuels over the next of 25% is likely to decrease by 1% per year but this is not sufficient to render them competitive. Blending biofuels is not likely to be economically viable for oil prices not exceeding $75/bbl, unless subsidies similar to those seen for biodiesel and ethanol, or other Government support mechanisms apply.

Currently low ethanol mixtures with gasoline (i.e. E10) are in use today; however for higher biofuels blended ratios, additional infrastructure will be required for wide-scale distribution, storage and re-fuelling, and possibly some engine modifications.

(FTF) references significant losses of operational performance in railway when diesel is blended with biodiesel.

Biofuel production costs vary over a wide range. The cheapest ethanol could be competitive in the market or even cheaper than petrol but this analysis is directly linked to the relative evolution of the food crop commodities market and the oil market from 50 up to 130 $/bbl; synthetic biofuels are up to a factor 2 more expensive than the commodity price for petrol/oil, in present conditions (FTF).

BTL technology is available in pilot scale at this moment, and scaling up to commercial scale is anticipated before 2020 (FTF).

(IATA) points out, based on EU and US projects, that current BTL costs are in a range of $1.05-1.84 a litre, with variations depending on the feedstock (in this case wood chips, wood waste, straw), local growing conditions and the processing of the biomass whereas (IEA) reported this cost $0.79 a litre, as the feedstock costs represent about 70 - 75 % of total cost (with conversion costs being about 10 %, and capital costs about 15 - 20 %, (FTF).

19.2.3 Synthetic fuels

According to (FTF) a GTL blend with diesel was found to be the most cost effective solution to replace oil based fuels. GTL is still a cost-competitive alternative to conventional oil products today. Cost reduction of future GTL plants might also be expected as a result of economies of scale.

19.2.4 Methane

Methane cars are in the same price range as diesel cars. Infrastructure for methane distribution has to be extended, with a new outlet in a filling station at a cost of the order 250,000 € (FTF). Biomethane could have comparable cost at fabrication in industrial scale.

19.2.5 LPG

LPG vehicles are being offered as bi-fuel vehicles at an additional price of about 2,000€ cost. As the LPG refuelling infrastructure exist in some countries, the additional price of LPG vehicles could be compensated by the differential price of LPG which mainly depend on the applied excise taxes.

19.2.6 Hydrogen

The high cost of materials and fuel cell components are among the main barriers to commercialization. The costs of fuel cell power trains in demonstration vehicles are around ten times higher than anticipated future costs if fuel cells are produced at large-scale. There are two key reasons for the currently high costs. Firstly, core fuel cell components are intrinsically expensive: further basic research is required to find new lower-cost fuel cell materials. Secondly, current fuel cell stack designs are not suited for high-volume production. Assuming technologies suitable for mass production, an 80 kW fuel cell power train would cost 30,000 € (DET06) in the future.

The cost of delivering compressed hydrogen depends strongly on the mode of transport and on the distance. According to available studies (DET06, WETO), the distribution cost by truck ranges between 10 and 30 €/GJ and by pipeline between 6 and 20 €/GJ. The large range of cost estimations reflects the variation with distance and the limited experience in large-scale hydrogen transport and distribution applications. It is likely that learning effects and economies of scale will reduce the cost in the future.

The cost of using fuel cell vehicles is dominated by a fixed cost component. The variable cost, even with the present cost structure, is lower for FC vehicles than for conventional ones. Based on WETO, assuming a hydrogen price of 40 €/GJ and a gasoline price of 30 €/GJ and specific consumptions of PEMFC vehicles and standard internal combustion vehicles of 0.0014 GJ/km and 0.0023 GJ/km, the corresponding variable costs are around 0.055 €/km and 0.070 €/km, respectively. The additional cost of hydrogen storage and fuel handling is reported to be roughly 60 €/kW for a H2-fuelled vehicle and 3 000 €/kW for FC vehicles fuelled by compressed natural gas with an on-board reformer. These cost estimates translate into a total levelised cost per kilometre of about 3.5 €/km for the PEMFC vehicle, 4.5 €/km for the on-board natural gas reforming FC vehicle and 0.25 €/km for the standard gasoline ICE vehicle.

The European Hydrogen & Fuel Cell Technology Platform foresees specific costs of the PEMFC power train falling to around 100 €/kW by 2020, for an overall production of 150000 vehicles a year. Levelised costs of a FC vehicle covering a distance of 15000 km per year, could then lie between 0.2 and 0.3 €/km, assuming that the hydrogen price also falls from 40 €/GJ to 20 €/GJ.

19.3 Co-impacts of Alternative Fuel Production

The alternative fuels and the corresponding vehicle technologies have various environmental co-impacts on air quality and other external cost factors.

19.3.1 Impacts on air quality

The use of biofuels can have varying co-impacts on pollution emission levels. Blending ethanol into gasoline generally lowers CO, HC and PM emissions although at some blend levels, evaporative HC emissions can increase. Biodiesel blends result in lower PM, CO and HC emissions compared to petroleum diesel.

For both ethanol and biodiesel, changes in NO_X emissions are generally minor and can go up or down depending on conditions and engine calibration. Upstream emissions from biofuel production depend on the type of feedstock used, associated changes in land use, harvesting and processing methods, transport distances, and the combustion control technologies applied.

Zero-emission vehicles powered by electricity or hydrogen fuel cells imply pollution only indirectly through the production of the electricity or hydrogen used.

19.3.2 Impacts on water use

Irrigation for biofuel crops is the primary cause of water consumption associated with ethanol and biodiesel production using conventional feedstock. E85 produced from irrigated corn is estimated to consume 10 to 25 times the amount of water used to produce conventional gasoline and approximately 14 times more than E85 made with non-irrigated corn.

19.3.3 Impacts on land use

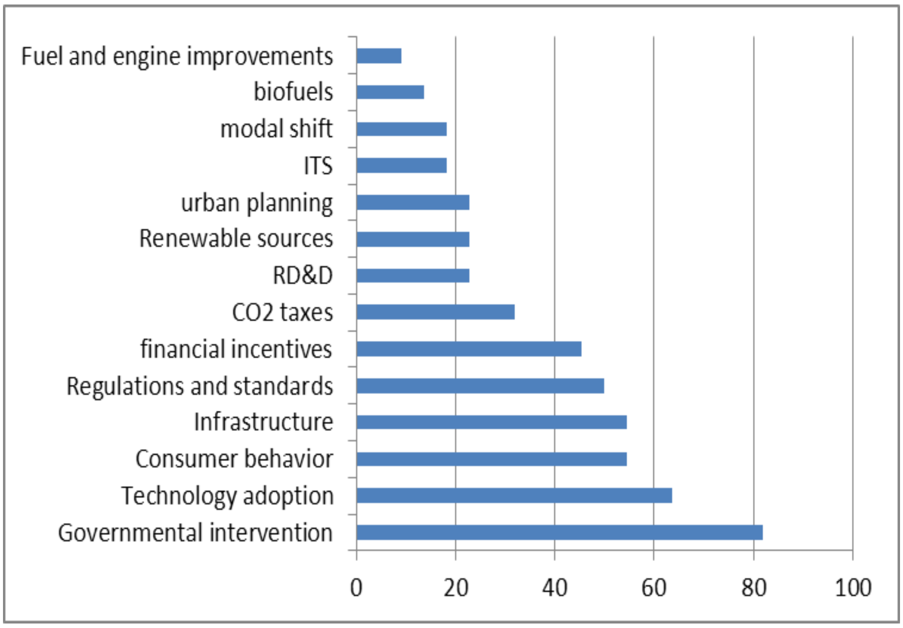
Biofuels are significantly more land-intensive than other fuel technologies and that they sometimes compete for a relatively limited stock of arable land (FTF, TEC09, E4tech).

19.4 Policy measures recommendations

The reviewed studies recognise that significant policy packages need to deploy in order to ensure transition towards structural changes in transportation and towards decarbonisation. The policy measures analysed range from market instruments, to standards and regulations, up to technical specifications and R&D support.

Figure 25 shows the presence frequency of each category of policy measures in the reviewed studies.

Figure 25: Popularity of category of policy measures



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20 Annex D: Model Results for EU27

EU27: Reference scenario **SUMMARY (A)**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6511**	**7125**	**7555**	**7986**	**8386**	**8724**	**9014**	**9265**	**9453**	**1.5**	**1.0**	**0.7**	**0.5**
Public road transport	526	545	574	601	623	642	657	670	680	687	1.0	0.7	0.4	0.3
Private cars	4309	4472	4860	5077	5296	5500	5681	5822	5936	6003	1.3	0.8	0.6	0.3
2wheelers	150	155	166	178	188	197	205	211	216	219	1.4	1.0	0.7	0.4
Passenger light duty vehicles	227	239	263	278	292	306	318	327	335	339	1.5	1.0	0.7	0.4
Rail	461	482	523	565	605	642	678	713	744	767	1.6	1.3	1.1	0.7
Aviation	527	577	697	814	937	1053	1138	1223	1306	1388	3.5	2.6	1.5	1.3
Inland navigation	40	41	42	44	45	46	47	48	49	50	0.7	0.6	0.4	0.3
Freight transport activity (Gtkm)	**2495**	**2663**	**2958**	**3125**	**3292**	**3438**	**3568**	**3688**	**3789**	**3863**	**1.6**	**1.0**	**0.7**	**0.5**
Heavy duty vehicles	1740	1879	2107	2219	2337	2442	2536	2623	2699	2753	1.7	1.0	0.7	0.5
Freight light duty vehicles	60	61	65	66	70	75	79	82	85	87	0.7	1.3	0.9	0.6
Rail	414	440	488	525	555	579	601	621	638	652	1.8	1.0	0.7	0.5
Inland waterway navigation	280	282	298	315	330	342	353	361	367	370	1.1	0.8	0.5	0.3
Final Energy Demand (ktoe)	**362402**	**373002**	**395004**	**398072**	**396843**	**392028**	**388627**	**387787**	**388315**	**386645**	**0.7**	**-0.2**	**-0.1**	**0.0**
by transport mode														
Passenger transport	**254276**	**258946**	**268839**	**268771**	**266609**	**262695**	**258427**	**256471**	**256255**	**254536**	**0.4**	**-0.2**	**-0.2**	**-0.1**
Public road transport	5028	5201	5417	5485	5361	5279	5215	5137	5009	4866	0.5	-0.4	-0.3	-0.5
Private cars	169568	170851	172621	167040	161607	157354	154151	151580	150048	147130	-0.2	-0.6	-0.4	-0.3
2wheelers	7094	7192	7396	7648	7583	7663	7571	7517	7433	7255	0.6	0.0	-0.2	-0.4
Passenger light duty vehicles	18828	19760	20812	20767	20752	20850	20794	20627	20470	20164	0.5	0.0	-0.1	-0.2
Rail	1960	1985	2132	2199	2291	2282	2284	2232	2144	2091	1.0	0.4	-0.2	-0.7
Aviation	49703	51803	58236	63343	66666	66864	65974	66909	68662	70532	2.0	0.5	0.0	0.5
Inland navigation	2094	2153	2225	2289	2350	2402	2439	2469	2488	2498	0.6	0.5	0.3	0.1
Freight transport	**108126**	**114057**	**126164**	**129302**	**130234**	**129333**	**130200**	**131317**	**132060**	**132109**	**1.3**	**0.0**	**0.2**	**0.1**
Heavy duty vehicles	92279	98192	109476	112975	113638	112659	113209	114319	115186	115481	1.4	0.0	0.1	0.1
Freight light duty vehicles	5079	5172	5276	5027	5137	5263	5316	5351	5377	5356	-0.3	0.5	0.2	0.0
Rail	7476	7384	7947	7617	7560	7363	7507	7386	7186	6958	0.3	-0.3	0.0	-0.6
Inland waterway navigation	3292	3309	3465	3682	3899	4048	4168	4260	4311	4314	1.1	1.0	0.5	0.1
by fuel														
Oil products	**352414**	**353413**	**367009**	**359057**	**354873**	**345622**	**340691**	**339381**	**339873**	**338771**	**0.2**	**-0.4**	**-0.2**	**0.0**
Gasoline	114297	106579	103207	97217	94370	92613	90971	89388	89211	88163	-0.9	-0.5	-0.4	-0.1
Diesel	182919	188764	197567	190018	185629	178164	175711	175046	174164	172533	0.1	-0.6	-0.2	-0.1
Kerosene	49703	51803	58236	63343	66666	66864	65974	66909	68662	70532	2.0	0.5	0.0	0.5
Liquefied Petroleum Gas	4520	5351	7114	7625	7387	7194	7287	7342	7190	6941	3.6	-0.6	0.2	-0.6
Residual fuel oil	974	916	884	854	821	788	749	695	646	603	-0.7	-0.8	-1.2	-1.4
Biofuels	**3129**	**11983**	**19461**	**29970**	**32284**	**36471**	**37635**	**38019**	**38121**	**37684**	**9.6**	**2.0**	**0.4**	**-0.1**
Bio Gasoline	581	3339	5231	8564	9050	10747	11260	11396	11541	11445	9.9	2.3	0.6	0.0
Bio Diesel	2548	8644	14229	21406	23234	25724	26375	26623	26580	26239	9.5	1.9	0.3	-0.1
Bio Kerosene	0	0	0	0	0	0	0	0	0	0				
DME	0	0	0	0	0	0	0	0	0	0	-6.1	5.8	1.0	0.8
Bio Heavy	0	0	0	0	0	0	0	0	0	0				
Biogas	0	0	0	0	0	0	0	0	0	0	-7.3	41.2	5.4	5.4
Electricity	6353	6781	7453	7762	8356	8554	8901	8984	8953	8866	**1.4**	**1.0**	**0.5**	**-0.1**
Natural Gas	506	825	1081	1284	1330	1380	1399	1403	1367	1324	**4.5**	**0.7**	**0.2**	**-0.6**
Hydrogen	0	0	0	0	0	0	0	0	0	0		**40.8**	**7.8**	**2.2**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.7**	**35.6**	**33.4**	**31.3**	**29.6**	**28.5**	**27.7**	**26.9**	**-1.1**	**-1.3**	**-1.0**	**-0.5**
Public road transport	9.6	9.5	9.4	9.1	8.6	8.2	7.9	7.7	7.4	7.1	-0.4	-1.0	-0.7	-0.8
Private cars	39.4	38.2	35.5	32.9	30.5	28.6	27.1	26.0	25.3	24.5	-1.5	-1.4	-0.9	-0.6
2wheelers	47.3	46.4	44.6	43.0	40.3	38.9	37.0	35.7	34.5	33.1	-0.8	-1.0	-0.8	-0.7
Passenger light duty vehicles	82.8	82.7	79.1	74.8	71.0	68.1	65.4	63.0	61.2	59.4	-1.0	-0.9	-0.8	-0.6
Rail	4.3	4.1	4.1	3.9	3.8	3.6	3.4	3.1	2.9	2.7	-0.5	-0.9	-1.3	-1.4
Aviation	94.3	89.8	83.6	77.8	71.2	63.5	58.0	54.7	52.6	50.8	-1.4	-2.0	-1.5	-0.7
Inland navigation	53.0	52.8	52.6	52.4	52.2	52.0	51.7	51.3	50.9	50.4	-0.1	-0.1	-0.1	-0.2
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**42.6**	**41.4**	**39.6**	**37.6**	**36.5**	**35.6**	**34.8**	**34.2**	**-0.3**	**-0.9**	**-0.5**	**-0.4**
Heavy duty vehicles	53.0	52.3	52.0	50.9	48.6	46.1	44.6	43.6	42.7	41.9	-0.3	-1.0	-0.6	-0.4
Freight light duty vehicles	84.8	84.4	80.8	76.6	72.9	70.1	67.3	65.0	63.1	61.4	-1.0	-0.9	-0.8	-0.6
Rail	18.1	16.8	16.3	14.5	13.6	12.7	12.5	11.9	11.3	10.7	-1.4	-1.3	-0.7	-1.1
Inland waterway navigation	11.7	11.7	11.6	11.7	11.8	11.8	11.8	11.8	11.7	11.6	0.0	0.1	0.0	-0.1
CO$_2$ EMISSIONS (in ktons CO$_2$)	**1053078**	**1057807**	**1099320**	**1075812**	**1063411**	**1035562**	**1020857**	**1017039**	**1018391**	**1015037**	**0.2**	**-0.4**	**-0.2**	**0.0**
Passenger transport	740076	737781	753607	734412	724351	705044	690544	684638	684331	680650	0.0	-0.4	-0.3	-0.1
Public road transport	15225	15248	15489	15078	14593	14118	13870	13635	13289	12915	-0.1	-0.7	-0.3	-0.5
Private cars	493354	484038	478802	447404	428945	410439	399702	392084	387683	380124	-0.8	-0.9	-0.5	-0.3
2wheelers	20311	20136	20351	20315	19963	19801	19420	19215	18972	18517	0.1	-0.3	-0.3	-0.4
Passenger light duty vehicles	56340	57216	58674	56150	55456	54677	54176	53588	53118	52316	-0.2	-0.3	-0.2	-0.2
Rail	1085	966	817	654	539	403	293	168	66	8	-3.8	-4.7	-8.4	-26.5
Aviation	147321	153545	172613	187747	197599	198186	195546	198319	203514	209057	2.0	0.5	0.0	0.5
Inland navigation	6439	6632	6861	7064	7256	7420	7537	7629	7687	7713	0.6	0.5	0.3	0.1
Freight transport	313002	320026	345713	341400	339060	330518	330313	332401	334061	334387	**0.6**	**-0.3**	**0.1**	**0.1**
Heavy duty vehicles	279315	287925	313002	310982	309402	301428	301300	303688	305806	306698	0.8	-0.3	0.1	0.1
Freight light duty vehicles	15142	14912	14824	13580	13710	13782	13826	13877	13925	13869	-0.9	0.1	0.1	0.0
Rail	8377	6979	7200	5488	3937	2844	2357	1730	1072	557	-2.4	-6.4	-4.8	-10.7
Inland waterway navigation	10168	10211	10687	11350	12011	12463	12830	13106	13258	13263	1.1	0.9	0.5	0.1

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B) **EU27: Reference scenario**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260718**	**279323**	**291193**	**303145**	**316263**	**326337**	**334206**	**340368**	**344217**	**1.1**	**0.8**	**0.6**	**0.3**
Diesel Conventional	87565	101830	111535	115597	116472	114881	111746	109480	107574	105155	1.3	-0.1	-0.5	-0.4
Diesel Hybrid	0	149	809	2621	6500	11775	17607	22517	26506	30107	33.2	16.2	6.7	2.9
Diesel plug-in hybrid	0	0	7	23	38	49	55	56	54	52		7.9	1.4	-0.8
Gasoline Conventional	150450	149273	153536	155961	158351	160363	159035	156666	154842	152412	0.4	0.3	-0.2	-0.3
Gasoline Hybrid	24	144	856	3106	8042	15271	23299	30311	36144	41300	36.0	17.3	7.1	3.1
Gasoline plug-in hybrid	0	0	5	18	29	38	42	45	45	45		7.6	1.7	0.0
LPG	4849	8194	10993	11828	11451	11428	11920	12354	12373	12303	3.7	-0.3	0.8	0.0
CNG	718	1123	1548	1948	2113	2243	2347	2422	2407	2360	5.7	1.4	0.8	-0.3
E85	0	6	33	87	145	210	280	349	416	477	30.2	9.2	5.2	3.2
Electric	0	0	1	2	4	5	5	6	6	6		7.3	1.9	0.6
Hydrogen	0	0	0	0	0	0	0	0	1	1		36.3	6.3	1.2
2wheelers	**31568**	**33229**	**36289**	**39510**	**42414**	**44917**	**46943**	**48463**	**49757**	**50620**	**1.7**	**1.3**	**0.8**	**0.4**
Gasoline	31568	33229	36289	39510	42414	44917	46943	48463	49757	50620	1.7	1.3	0.8	0.4
Electricity	0	0	0	0	0	0	0	0	0	0		23.3	9.5	2.5
HDVs, buses and coaches	**8580**	**9475**	**10441**	**10970**	**11456**	**12143**	**12630**	**13077**	**13422**	**13704**	**1.5**	**1.0**	**0.7**	**0.5**
Diesel Conventional	8565	9454	10405	10899	11340	11969	12397	12782	13062	13279	1.4	0.9	0.7	0.4
Diesel Hybrid	0	5	20	53	102	156	213	274	338	402	27.4	11.3	5.8	3.9
LPG	2	2	2	3	3	4	5	6	7	7	2.7	5.7	2.8	2.1
CNG	13	14	14	14	10	13	15	15	16	15	-0.1	-0.9	1.7	0.0
Electric	0	0	0	0	0	0	0	0	0	0		21.4	10.0	2.8
Hydrogen	0	0	0	0	0	0	0	0	0	0		52.9	12.7	4.5
Total annual cost excl. disutility (in million Euro'08)	**2420688**	**2603483**	**2776754**	**3027292**	**3253132**	**3405792**	**3548112**	**3676040**	**3780665**	**3872332**	**1.5**	**1.2**	**0.8**	**0.5**
Passenger transport	**1992952**	**2130638**	**2247945**	**2442264**	**2626676**	**2749237**	**2863966**	**2965070**	**3046772**	**3115621**	**1.4**	**1.2**	**0.8**	**0.5**
Public road transport	47158	52712	55622	59096	62863	65099	66808	68224	69806	71046	1.1	1.0	0.5	0.4
Private cars	1590129	1691997	1757964	1887127	2008631	2081674	2158302	2222375	2267229	2300110	1.1	1.0	0.7	0.3
2wheelers	46744	48919	53109	59528	67246	70065	72941	75795	78809	80102	2.0	1.6	0.8	0.6
Passenger light duty vehicles	113667	124497	133898	144122	153872	162102	168754	174224	178821	182810	1.5	1.2	0.7	0.5
Rail	74543	78181	81076	83654	86063	88130	89030	91349	94596	96696	0.7	0.5	0.4	0.6
Aviation	112942	126145	157584	199178	237860	271580	297166	321723	345723	372603	4.7	3.1	1.7	1.5
Inland navigation	7770	8186	8693	9560	10142	10586	10965	11380	11788	12254	1.6	1.0	0.7	0.7
Freight transport	**427736**	**472846**	**528809**	**585027**	**626455**	**656555**	**684147**	**710970**	**733893**	**756711**	**2.2**	**1.2**	**0.8**	**0.6**
Heavy duty vehicles	298800	338420	382077	426078	458261	480666	504303	527343	547866	567597	2.3	1.2	0.9	0.7
Freight light duty vehicles	31420	33154	34484	35265	38527	41363	43666	45849	47717	49370	0.6	1.6	1.0	0.7
Rail	55914	58727	66681	74328	77288	79864	79699	79544	78533	78594	2.4	0.7	0.0	-0.1
Inland waterway navigation	41602	42545	45566	49357	52380	54662	56478	58233	59777	61150	1.5	1.0	0.6	0.5
External costs (in million Euro'08) (1)	**447714**	**404180**	**416865**	**431120**	**445253**	**463715**	**481831**	**496859**	**509728**	**517516**	**0.6**	**0.7**	**0.7**	**0.4**
Disutility costs (in million Euro'08)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**				
Passenger transport	0	0	0	0	0	0	0	0	0	0				
Freight transport	0	0	0	0	0	0	0	0	0	0				
Total costs (incl. disutility and external costs)	**2420688**	**2603483**	**2776754**	**3027292**	**3253132**	**3405792**	**3548112**	**3676040**	**3780665**	**3872332**	**1.5**	**1.2**	**0.8**	**0.5**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: Renew fuel cell success with CO2 standards **SUMMARY (A)**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6511**	**7072**	**7408**	**7678**	**8202**	**8532**	**8803**	**9048**	**9260**	**1.3**	**1.0**	**0.7**	**0.5**
Public road transport	526	545	564	598	628	644	659	676	684	686	0.9	0.7	0.5	0.1
Private cars	4309	4472	4821	4936	4988	5301	5474	5606	5760	5880	1.0	0.7	0.6	0.5
2wheelers	150	155	166	176	184	194	200	204	209	214	1.3	1.0	0.5	0.5
Passenger light duty vehicles	227	239	259	270	279	298	308	317	324	330	1.2	1.0	0.6	0.4
Rail	461	482	524	567	614	644	680	718	754	779	1.6	1.3	1.1	0.8
Aviation	527	577	700	819	941	1076	1164	1234	1267	1319	3.6	2.8	1.4	0.7
Inland navigation	40	41	40	42	44	45	47	48	50	52	0.3	0.8	0.7	0.7
Freight transport activity (Gtkm)	**2495**	**2664**	**2885**	**3070**	**3226**	**3373**	**3485**	**3591**	**3655**	**3683**	**1.4**	**0.9**	**0.6**	**0.3**
Heavy duty vehicles	1740	1880	2016	2135	2235	2330	2398	2465	2496	2492	1.3	0.9	0.6	0.1
Freight light duty vehicles	60	61	64	65	70	76	79	83	85	86	0.5	1.6	0.9	0.5
Rail	414	440	503	550	582	612	639	663	684	706	2.2	1.1	0.8	0.6
Inland waterway navigation	280	282	303	321	339	355	369	381	390	398	1.3	1.0	0.7	0.4
Final Energy Demand (ktoe)	**362402**	**372960**	**383878**	**367306**	**336005**	**320395**	**293759**	**269231**	**250242**	**235167**	**-0.2**	**-1.4**	**-1.7**	**-1.3**
by transport mode														
Passenger transport	**254276**	**258846**	**265332**	**249531**	**225468**	**214348**	**191200**	**169425**	**154179**	**145532**	**-0.4**	**-1.5**	**-2.3**	**-1.5**
Public road transport	5028	5201	5191	5100	4700	4272	3952	3736	3554	3378	-0.2	-1.8	-1.3	-1.0
Private cars	169568	170749	169842	151051	126681	116779	98430	79583	68481	62365	-1.2	-2.5	-3.8	-2.4
2wheelers	7094	7192	7386	7243	6851	6295	5165	4010	2919	2216	0.1	-1.4	-4.4	-5.8
Passenger light duty vehicles	18828	19762	20141	18119	15770	14276	12306	11157	10387	9832	-0.9	-2.4	-2.4	-1.3
Rail	1960	1985	2130	2192	2289	2252	2233	2179	2087	2023	1.0	0.3	-0.3	-0.7
Aviation	49703	51804	58589	63677	66945	68186	66799	66374	64296	63246	2.1	0.7	-0.3	-0.5
Inland navigation	2094	2153	2053	2148	2234	2286	2314	2387	2454	2472	0.0	0.6	0.4	0.4
Freight transport	**108126**	**114114**	**118546**	**117775**	**110536**	**106047**	**102559**	**99806**	**96063**	**89635**	**0.3**	**-1.0**	**-0.6**	**-1.1**
Heavy duty vehicles	92279	98249	101999	101924	94676	90428	87021	84502	80994	74905	0.4	-1.2	-0.7	-1.2
Freight light duty vehicles	5079	5174	5054	4442	4093	3758	3281	3027	2829	2676	-1.5	-1.7	-2.1	-1.2
Rail	7476	7383	8010	7691	7788	7671	7909	7790	7667	7454	0.4	0.0	0.2	-0.4
Inland waterway navigation	3292	3308	3483	3718	3979	4190	4348	4487	4573	4599	1.2	1.2	0.7	0.2
by fuel														
Oil products	**352414**	**353487**	**355833**	**322083**	**280964**	**252263**	**215275**	**174398**	**134498**	**104891**	**-0.9**	**-2.4**	**-3.6**	**-5.0**
Gasoline	114297	106546	101676	83528	65055	52896	38022	24587	16469	12487	-2.4	-4.5	-7.4	-6.6
Diesel	182919	188835	185474	161580	134803	115109	97608	78519	61010	44040	-1.5	-3.3	-3.8	-5.6
Kerosene	49703	51804	58589	63677	66945	67796	64643	58683	45690	36854	2.1	0.6	-1.4	-4.5
Liquefied Petroleum Gas	4520	5385	9252	12501	13406	15761	14380	12087	10906	11102	8.8	2.3	-2.6	-0.8
Residual fuel oil	974	916	843	797	756	701	622	522	422	408	-1.4	-1.3	-2.9	-2.4
Biofuels	**3129**	**11984**	**18230**	**29427**	**32154**	**36028**	**37685**	**46103**	**61103**	**70797**	**9.4**	**2.0**	**2.5**	**4.4**
Bio Gasoline	581	3338	5102	7722	7765	8269	8090	7827	7470	6482	8.8	0.7	-0.5	-1.9
Bio Diesel	2548	8646	13128	21705	24385	26995	26838	29648	33163	33843	9.6	2.2	0.9	1.3
Bio Kerosene	0	0	0	0	0	390	2157	7690	18606	26392			34.7	13.1
DME	0	0	0	0	3	292	453	691	1456	3425	9.1	91.6	9.0	17.4
Bio Heavy	0	0	0	0	0	8	43	106	186	197			29.6	6.4
Biogas	0	0	0	0	0	75	103	141	222	458	42.9	121.5	6.6	12.5
Electricity	6353	6780	7702	9695	12106	14855	18987	22156	24212	25601	**3.6**	**4.4**	**4.1**	**1.5**
Natural Gas	506	710	2112	4344	6608	10558	10870	9913	9431	8076	**19.9**	**9.3**	**-0.6**	**-2.0**
Hydrogen	0	0	0	1757	4172	6691	10942	16661	20998	25801		**14.3**	**9.6**	**4.5**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.5**	**33.7**	**29.4**	**26.1**	**22.4**	**19.2**	**17.0**	**15.7**	**-1.6**	**-2.5**	**-3.0**	**-2.0**
Public road transport	9.6	9.5	9.2	8.5	7.5	6.6	6.0	5.5	5.2	4.9	-1.1	-2.5	-1.8	-1.1
Private cars	39.4	38.2	35.2	30.6	25.4	22.0	18.0	14.2	11.9	10.6	-2.2	-3.2	-4.3	-2.9
2wheelers	47.3	46.4	44.5	41.2	37.2	32.4	25.9	19.6	14.0	10.3	-1.2	-2.4	-4.9	-6.2
Passenger light duty vehicles	82.8	82.7	77.9	67.1	56.6	48.0	39.9	35.2	32.1	29.8	-2.1	-3.3	-3.0	-1.7
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.1	63.3	57.4	53.8	50.7	48.0	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.5	49.7	49.3	48.6	47.8	-0.3	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**41.1**	**38.4**	**34.3**	**31.4**	**29.4**	**27.8**	**26.3**	**24.3**	**-1.1**	**-2.0**	**-1.2**	**-1.3**
Heavy duty vehicles	53.0	52.3	50.6	47.7	42.4	38.8	36.3	34.3	32.4	30.1	-0.9	-2.0	-1.2	-1.3
Freight light duty vehicles	84.8	84.4	79.5	68.9	58.7	49.6	41.4	36.7	33.4	31.0	-2.0	-3.2	-3.0	-1.7
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.7	11.2	10.6	-1.8	-1.1	-0.6	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	-0.1	0.2	0.0	-0.2
CO_2 EMISSIONS (in ktons CO_2)	**1053078**	**1057754**	**1066707**	**969912**	**851986**	**774466**	**665626**	**542225**	**422118**	**329687**	**-0.9**	**-2.2**	**-3.5**	**-4.9**
Passenger transport	740076	737556	742925	667007	581577	530157	440220	341613	254758	203246	-1.0	-2.3	-4.3	-5.1
Public road transport	15225	15249	14819	13950	12388	10514	8935	7620	6561	5356	-0.9	-2.8	-3.2	-3.5
Private cars	493354	483807	470572	390841	307123	263758	195667	125296	85356	65578	-2.1	-3.9	-7.2	-6.3
2wheelers	20311	20134	20334	19231	17945	15408	11782	7997	4770	2976	-0.5	-2.2	-6.3	-9.4
Passenger light duty vehicles	56340	57220	56397	46970	38271	32167	25299	20510	17360	15144	-2.0	-3.7	-4.4	-3.0
Rail	1085	967	814	649	532	398	267	140	48	4	-3.9	-4.8	-9.9	-29.3
Aviation	147321	153548	173658	188738	198424	200947	191601	173937	135426	109235	2.1	0.6	-1.4	-4.5
Inland navigation	6439	6631	6330	6628	6894	6964	6668	6112	5237	4953	0.0	0.5	-1.3	-2.1
Freight transport	313002	320197	323782	302905	270409	244309	225406	200612	167360	126441	**-0.6**	**-2.1**	**-2.0**	**-4.5**
Heavy duty vehicles	279315	288093	291926	274836	244279	220240	203955	182182	152180	112847	-0.5	-2.2	-1.9	-4.7
Freight light duty vehicles	15142	14919	14106	11529	9961	8491	6795	5640	4793	4176	-2.5	-3.0	-4.0	-3.0
Rail	8377	6977	7010	5085	3917	2868	2223	1474	830	395	-3.1	-5.6	-6.4	-12.3
Inland waterway navigation	10168	10209	10740	11455	12252	12710	12432	11315	9557	9022	1.2	1.0	-1.2	-2.2

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B)										EU27: Renew fuel cell success with CO2 standards				
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**'10-'20**	**'20-'30**	**'30-'40**	**'40-'50**
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260703**	**277080**	**283890**	**276741**	**296680**	**308260**	**315571**	**324713**	**332605**	**0.9**	**0.4**	**0.6**	**0.5**
Diesel Conventional	87565	101810	104918	84800	55375	40744	27085	15774	9696	7198	-1.8	-7.1	-9.1	-7.5
Diesel Hybrid	0	204	2257	11112	21214	24752	21286	15379	11603	9613	49.1	8.3	-4.6	-4.6
Diesel plug-in hybrid	0	0	749	7689	14314	19142	24523	26633	26906	26081		9.5	3.4	-0.2
Gasoline Conventional	150450	149253	150444	125949	86447	64603	41635	22622	12514	8651	-1.7	-6.5	-10.0	-9.2
Gasoline Hybrid	24	221	2407	14068	28353	34514	30893	23729	18843	15835	51.5	9.4	-3.7	-4.0
Gasoline plug-in hybrid	0	0	711	9172	18230	25863	35962	41762	42438	40236		10.9	4.9	-0.4
LPG	4849	8234	13118	17235	18185	21403	19917	15562	12411	11259	7.7	2.2	-3.1	-3.2
CNG	718	976	2454	5126	8088	11698	11761	9376	7528	6479	18.0	8.6	-2.2	-3.6
E85	0	6	17	88	457	946	1283	1285	1236	1168	31.0	26.8	3.1	-1.0
Electric	0	0	4	2341	9225	23935	45939	69153	86529	97450		26.2	11.2	3.5
Hydrogen	0	0	1	6309	16854	29077	47976	74296	95010	108635		16.5	9.8	3.9
2wheelers	**31568**	**33227**	**36238**	**38923**	**41383**	**43818**	**45267**	**46214**	**47150**	**48173**	**1.6**	**1.2**	**0.5**	**0.4**
Gasoline	31568	33227	36238	37198	37986	35907	30486	23087	15693	10763	1.1	-0.4	-4.3	-7.3
Electricity	0	0	0	1725	3397	7912	14781	23126	31457	37410		16.5	11.3	4.9
HDVs, buses and coaches	**8580**	**9479**	**10155**	**10631**	**11000**	**11640**	**12074**	**12443**	**12615**	**12654**	**1.2**	**0.9**	**0.7**	**0.2**
Diesel Conventional	8565	9457	10026	10057	8280	7010	5817	5085	4711	4147	0.6	-3.5	-3.2	-2.0
Diesel Hybrid	0	6	69	420	2428	3970	5191	5774	5657	5277	54.0	25.2	3.8	-0.9
LPG	2	2	14	40	79	142	215	337	490	653	36.5	13.5	9.0	6.9
CNG	13	15	46	84	135	275	407	542	679	740	19.1	12.6	7.0	3.2
Electric	0	0	0	25	67	210	363	528	695	899		23.7	9.6	5.5
Hydrogen	0	0	0	4	11	33	81	176	382	938		23.6	18.1	18.2
Total annual cost excl. disutility (in million Euro'08)	**2421033**	**2603713**	**2804815**	**3062116**	**3287379**	**3464798**	**3641987**	**3809450**	**3962249**	**4071631**	**1.6**	**1.2**	**1.0**	**0.7**
Passenger transport	**1993298**	**2130926**	**2262609**	**2467149**	**2650693**	**2799739**	**2944892**	**3081734**	**3203894**	**3280638**	**1.5**	**1.3**	**1.0**	**0.6**
Public road transport	47158	52715	56138	60175	64880	65673	67256	68862	70525	71693	1.3	0.9	0.5	0.4
Private cars	1590475	1692338	1771677	1913975	2041011	2144303	2247217	2338999	2406668	2434835	1.2	1.1	0.9	0.4
2wheelers	46744	48915	52918	59402	66585	69191	74011	78705	83750	86287	2.0	1.5	1.3	0.9
Passenger light duty vehicles	113667	124439	135297	143859	149271	157077	166266	174470	182684	188673	1.5	0.9	1.1	0.8
Rail	74543	78186	81208	84088	87394	88075	88716	91255	94941	97056	0.7	0.5	0.4	0.6
Aviation	112942	126148	156463	195894	231220	264885	290541	318102	353288	389345	4.5	3.1	1.8	2.0
Inland navigation	7770	8185	8907	9755	10333	10535	10885	11341	12038	12749	1.8	0.8	0.7	1.2
Freight transport	**427736**	**472787**	**542206**	**594967**	**636687**	**665059**	**697096**	**727716**	**758355**	**790992**	**2.3**	**1.1**	**0.9**	**0.8**
Heavy duty vehicles	298800	338403	392572	433257	465458	486549	513100	538396	564359	591581	2.5	1.2	1.0	0.9
Freight light duty vehicles	31420	33154	34518	35614	39015	41740	44688	47721	50238	52030	0.7	1.6	1.3	0.9
Rail	55914	58699	67840	75048	77785	79853	79975	80174	79904	80881	2.5	0.6	0.0	0.1
Inland waterway navigation	41602	42531	47276	51047	54428	56916	59333	61425	63854	66501	1.8	1.1	0.8	0.8
External costs (in million Euro'08) (1)	**447714**	**404190**	**409317**	**414379**	**428458**	**444573**	**445712**	**448020**	**451614**	**454394**	**0.2**	**0.7**	**0.1**	**0.1**
Disutility costs (in million Euro'08)	**0**	**84**	**31920**	**58254**	**111666**	**76536**	**87457**	**96454**	**106465**	**115066**	**92.3**	**2.8**	**2.3**	**1.8**
Passenger transport	0	75	14009	42271	90792	56114	61877	67317	67884	62828	88.3	2.9	1.8	-0.7
Freight transport	0	9	17912	15983	20874	20422	25580	29137	38581	52238	111.3	2.5	3.6	6.0
Total costs (incl. disutility and external costs)	**2421033**	**2603797**	**2836735**	**3120370**	**3399045**	**3541334**	**3729445**	**3905904**	**4068714**	**4186696**	**1.8**	**1.3**	**1.0**	**0.7**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: Renew fuel cell success with energy efficiency standards **SUMMARY (A)**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	6240	6511	7072	7405	7659	8183	8531	8826	9062	9253	1.3	1.0	0.8	0.5
Public road transport	526	545	564	590	613	638	649	661	668	670	0.8	0.8	0.4	0.1
Private cars	4309	4472	4821	4942	4983	5287	5479	5640	5787	5887	1.0	0.7	0.6	0.4
2wheelers	150	155	166	176	185	195	203	205	208	211	1.3	1.0	0.5	0.3
Passenger light duty vehicles	227	239	259	270	278	297	308	318	326	333	1.2	0.9	0.7	0.5
Rail	461	482	524	567	614	645	681	719	755	782	1.6	1.3	1.1	0.8
Aviation	527	577	700	819	941	1076	1164	1235	1267	1318	3.6	2.8	1.4	0.7
Inland navigation	40	41	40	42	44	45	47	49	51	52	0.3	0.8	0.7	0.7
Freight transport activity (Gtkm)	2495	2664	2886	3070	3225	3372	3486	3592	3655	3682	1.4	0.9	0.6	0.2
Heavy duty vehicles	1740	1880	2016	2135	2234	2329	2399	2466	2495	2490	1.3	0.9	0.6	0.1
Freight light duty vehicles	60	61	64	64	70	76	79	83	86	88	0.5	1.6	0.9	0.6
Rail	414	440	503	550	582	612	638	663	684	707	2.2	1.1	0.8	0.6
Inland waterway navigation	280	282	303	321	339	355	369	380	390	398	1.3	1.0	0.7	0.4
Final Energy Demand (ktoe)	362402	372960	383569	366940	334974	318199	292593	268607	247287	226258	-0.2	-1.4	-1.7	-1.7
by transport mode														
Passenger transport	254276	258846	265332	249790	224756	212330	190563	169662	152622	138577	-0.4	-1.6	-2.2	-2.0
Public road transport	5028	5201	5191	4830	4310	3939	3568	3283	2998	2774	-0.7	-2.0	-1.8	-1.7
Private cars	169568	170749	169842	151446	126153	114640	97105	79658	68298	58556	-1.2	-2.7	-3.6	-3.0
2wheelers	7094	7192	7386	7359	7044	6797	6376	5132	3691	2360	0.2	-0.8	-2.8	-7.5
Passenger light duty vehicles	18828	19762	20141	18117	15751	14224	12160	10576	8747	7138	-0.9	-2.4	-2.9	-3.9
Rail	1960	1985	2130	2191	2289	2256	2237	2181	2092	2031	1.0	0.3	-0.3	-0.7
Aviation	49703	51804	58589	63694	66965	68181	66795	66437	64335	63235	2.1	0.7	-0.3	-0.5
Inland navigation	2094	2153	2053	2153	2243	2292	2322	2394	2462	2482	0.0	0.6	0.4	0.4
Freight transport	108126	114114	118237	117150	110218	105869	102031	98946	94665	87680	0.3	-1.0	-0.7	-1.2
Heavy duty vehicles	92279	98249	101690	101301	94358	90249	86520	83804	80051	73699	0.3	-1.1	-0.7	-1.3
Freight light duty vehicles	5079	5174	5054	4439	4091	3756	3256	2865	2374	1928	-1.5	-1.7	-2.7	-3.9
Rail	7476	7383	8010	7692	7790	7673	7907	7791	7668	7455	0.4	0.0	0.2	-0.4
Inland waterway navigation	3292	3308	3483	3718	3979	4191	4348	4486	4572	4598	1.2	1.2	0.7	0.2
by fuel														
Oil products	352414	353487	355547	322550	280177	249432	216648	178802	138276	104684	-0.9	-2.5	-3.3	-5.2
Gasoline	114297	106546	101676	83943	65019	51993	40307	29069	21463	15393	-2.4	-4.7	-5.6	-6.2
Diesel	182919	188835	185189	161632	134378	114317	100208	83623	66026	47647	-1.5	-3.4	-3.1	-5.5
Kerosene	49703	51804	58589	63694	66965	67791	64639	58740	45717	36847	2.1	0.6	-1.4	-4.6
Liquefied Petroleum Gas	4520	5385	9251	12482	13058	14629	10871	6848	4647	4388	8.8	1.6	-7.3	-4.4
Residual fuel oil	974	916	843	798	757	701	623	522	423	409	-1.4	-1.3	-2.9	-2.4
Biofuels	3129	11984	18209	28577	31934	36810	38958	49420	65119	73252	9.1	2.6	3.0	4.0
Bio Gasoline	581	3338	5102	7751	7746	8645	8883	9643	9316	7492	8.8	1.1	1.1	-2.5
Bio Diesel	2548	8646	13107	20825	24184	27407	27341	31183	35400	35496	9.2	2.8	1.3	1.3
Bio Kerosene	0	0	0	0	0	390	2156	7698	18617	26388			34.7	13.1
DME	0	0	0	0	3	290	457	705	1484	3464	9.0	91.7	9.3	17.3
Bio Heavy	0	0	0	0	0	8	43	106	186	197			29.6	6.4
Biogas	0	0	0	0	0	70	78	86	116	216	42.5	120.8	2.1	9.7
Electricity	6353	6780	7702	9854	12286	15151	19054	23699	27730	32114	3.8	4.4	4.6	3.1
Natural Gas	506	710	2111	4182	6315	9857	8281	6238	5149	4008	19.4	9.0	-4.5	-4.3
Hydrogen	0	0	0	1778	4262	6949	9652	10448	11014	12199		14.6	4.2	1.6
Vehicles efficiency														
Passenger transport (toe/Mpkm)	40.7	39.8	37.5	33.7	29.3	25.9	22.3	19.2	16.8	15.0	-1.6	-2.6	-3.0	-2.5
Public road transport	9.6	9.5	9.2	8.2	7.0	6.2	5.5	5.0	4.5	4.1	-1.5	-2.8	-2.2	-1.8
Private cars	39.4	38.2	35.2	30.6	25.3	21.7	17.7	14.1	11.8	9.9	-2.2	-3.4	-4.2	-3.4
2wheelers	47.3	46.4	44.5	41.7	38.0	34.8	31.4	25.0	17.7	11.2	-1.1	-1.8	-3.3	-7.7
Passenger light duty vehicles	82.8	82.7	77.9	67.0	56.6	47.9	39.5	33.2	26.8	21.4	-2.1	-3.3	-3.6	-4.3
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.1	63.4	57.4	53.8	50.8	48.0	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.5	49.7	49.3	48.6	47.8	-0.3	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	43.3	42.8	41.0	38.2	34.2	31.4	29.3	27.5	25.9	23.8	-1.1	-1.9	-1.3	-1.4
Heavy duty vehicles	53.0	52.3	50.4	47.4	42.2	38.7	36.1	34.0	32.1	29.6	-1.0	-2.0	-1.3	-1.4
Freight light duty vehicles	84.8	84.4	79.5	68.8	58.7	49.6	41.0	34.6	27.8	21.9	-2.0	-3.2	-3.5	-4.5
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.7	11.2	10.6	-1.8	-1.1	-0.6	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	-0.1	0.2	0.0	-0.2
CO$_2$ EMISSIONS (in ktons CO$_2$)	1053078	1057754	1065826	970892	849049	764834	664971	548623	425480	321878	-0.9	-2.4	-3.3	-5.2
Passenger transport	740076	737556	742925	668197	579430	521392	440235	349262	261887	200513	-1.0	-2.5	-3.9	-5.4
Public road transport	15225	15249	14819	13002	11090	9393	7641	6075	4631	3268	-1.6	-3.2	-4.3	-6.0
Private cars	493354	483807	470573	392489	305655	255048	194078	132952	96367	70571	-2.1	-4.2	-6.3	-6.1
2wheelers	20311	20134	20334	19566	18505	16735	15054	10822	6551	3294	-0.3	-1.6	-4.3	-11.2
Passenger light duty vehicles	56340	57220	56396	47059	38241	31902	24914	19039	13528	9187	-1.9	-3.8	-5.0	-7.0
Rail	1085	967	814	649	532	398	267	140	48	4	-3.9	-4.8	-9.9	-29.3
Aviation	147321	153548	173658	188790	198486	200933	191589	174104	135507	109215	2.1	0.6	-1.4	-4.6
Inland navigation	6439	6631	6330	6643	6922	6983	6691	6130	5255	4973	0.0	0.5	-1.3	-2.1
Freight transport	313002	320197	322901	302694	269619	243442	224736	199360	163592	121365	-0.6	-2.2	-2.0	-4.8
Heavy duty vehicles	279315	288093	291047	274618	243487	219406	203365	181370	149536	109482	-0.5	-2.2	-1.9	-4.9
Freight light duty vehicles	15142	14919	14105	11536	9962	8456	6718	5202	3672	2469	-2.5	-3.1	-4.7	-7.2
Rail	8377	6977	7010	5086	3917	2869	2222	1477	829	395	-3.1	-5.6	-6.4	-12.4
Inland waterway navigation	10168	10209	10740	11455	12253	12711	12431	11312	9556	9019	1.2	1.0	-1.2	-2.2

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B)										EU27: Renew fuel cell success with energy efficiency standards				
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260703**	**277080**	**284088**	**276553**	**295873**	**308069**	**317325**	**326294**	**333287**	**0.9**	**0.4**	**0.7**	**0.5**
Diesel Conventional	87565	101810	104918	85174	55100	39358	22480	8977	2352	577	-1.8	-7.4	-13.7	-24.0
Diesel Hybrid	0	204	2257	11015	21559	26004	31073	31684	28407	20906	49.0	9.0	2.0	-4.1
Diesel plug-in hybrid	0	0	749	7523	14453	19874	27193	38152	46562	51704		10.2	6.7	3.1
Gasoline Conventional	150450	149253	150444	126604	85668	61083	33951	12979	3013	649	-1.6	-7.0	-14.3	-25.9
Gasoline Hybrid	24	221	2407	13906	28794	35987	43053	44221	39890	28615	51.3	10.0	2.1	-4.3
Gasoline plug-in hybrid	0	0	711	9011	18446	26849	36719	49409	58343	62440		11.5	6.3	2.4
LPG	4849	8234	13118	17285	17809	19867	15244	8174	3253	1290	7.7	1.4	-8.5	-16.9
CNG	718	976	2454	4978	7786	10856	8768	4713	1814	635	17.7	8.1	-8.0	-18.2
E85	0	6	17	86	461	945	1407	1167	804	419	30.7	27.1	2.1	-9.7
Electric	0	0	4	2321	9386	24941	45027	69428	93145	123261		26.8	10.8	5.9
Hydrogen	0	0	1	6187	17093	30108	43153	48423	48711	42792		17.1	4.9	-1.2
2wheelers	**31568**	**33227**	**36238**	**39133**	**41626**	**44291**	**46291**	**46685**	**46995**	**47526**	**1.6**	**1.2**	**0.5**	**0.2**
Gasoline	31568	33227	36238	38037	39435	39878	39793	31874	21311	10733	1.4	0.5	-2.2	-10.3
Electricity	0	0	0	1096	2191	4412	6498	14811	25684	36793		14.9	12.9	9.5
HDVs, buses and coaches	**8580**	**9479**	**10156**	**10618**	**10975**	**11627**	**12047**	**12402**	**12565**	**12606**	**1.1**	**0.9**	**0.6**	**0.2**
Diesel Conventional	8565	9457	9961	9820	7976	6761	5542	4789	4369	3755	0.4	-3.7	-3.4	-2.4
Diesel Hybrid	0	6	134	605	2687	4196	5455	6066	5980	5632	59.7	21.4	3.8	-0.7
LPG	2	2	14	32	59	118	172	271	400	538	33.3	14.1	8.7	7.1
CNG	13	15	46	58	80	212	310	416	521	552	14.9	13.8	7.0	2.9
Electric	0	0	0	92	156	301	477	665	877	1123		12.6	8.2	5.4
Hydrogen	0	0	0	10	17	40	90	194	418	1006		14.8	17.2	17.9
Total annual cost excl. disutility (in million Euro'08)	**2421033**	**2603713**	**2804694**	**3061819**	**3288370**	**3467875**	**3645956**	**3804303**	**3952751**	**4074441**	**1.6**	**1.3**	**0.9**	**0.7**
Passenger transport	**1993298**	**2130926**	**2262609**	**2467025**	**2651729**	**2802778**	**2949035**	**3076959**	**3194586**	**3283384**	**1.5**	**1.3**	**0.9**	**0.7**
Public road transport	47158	52715	56138	60178	64827	65582	66993	68329	70017	71229	1.3	0.9	0.4	0.4
Private cars	1590475	1692338	1771676	1914182	2042875	2148889	2254528	2337015	2399385	2439754	1.2	1.2	0.8	0.4
2wheelers	46744	48915	52918	59042	65812	68038	71449	76185	82571	86657	1.9	1.4	1.1	1.3
Passenger light duty vehicles	113667	124439	135297	143888	149143	156647	165723	174318	181883	186285	1.5	0.9	1.1	0.7
Rail	74543	78186	81208	84023	87452	88253	88934	91324	95184	97416	0.7	0.5	0.3	0.6
Aviation	112942	126148	156463	195932	231239	264803	290479	318416	353469	389241	4.5	3.1	1.9	2.0
Inland navigation	7770	8185	8907	9780	10380	10567	10927	11372	12076	12802	1.8	0.8	0.7	1.2
Freight transport	**427736**	**472787**	**542085**	**594793**	**636641**	**665097**	**696921**	**727343**	**758165**	**791057**	**2.3**	**1.1**	**0.9**	**0.8**
Heavy duty vehicles	298800	338403	392456	433075	465391	486565	512965	538110	564224	591871	2.5	1.2	1.0	1.0
Freight light duty vehicles	31420	33154	34516	35601	39007	41744	44673	47644	50160	51793	0.7	1.6	1.3	0.8
Rail	55914	58699	67839	75066	77808	79857	79960	80180	79945	80913	2.5	0.6	0.0	0.1
Inland waterway navigation	41602	42531	47275	51051	54435	56931	59323	61409	63836	66480	1.8	1.1	0.8	0.8
External costs (in million Euro'08) (1)	**447714**	**404190**	**409190**	**413848**	**427225**	**443097**	**446889**	**452741**	**456503**	**456403**	**0.2**	**0.7**	**0.2**	**0.1**
Disutility costs (in million Euro'08)	**0**	**84**	**31810**	**59150**	**117817**	**82126**	**87220**	**89939**	**102614**	**116215**	**92.5**	**3.3**	**0.9**	**2.6**
Passenger transport	0	75	14010	43179	96653	61443	61933	61435	64457	64628	88.7	3.6	0.0	0.5
Freight transport	0	9	17800	15971	21164	20683	25287	28503	38157	51587	111.3	2.6	3.3	6.1
Total costs (incl. disutility and external costs)	**2421033**	**2603797**	**2836504**	**3120968**	**3406187**	**3550001**	**3733175**	**3894241**	**4055365**	**4190656**	**1.8**	**1.3**	**0.9**	**0.7**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: Renew battery success with CO2 standards														SUMMARY (A)
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6511**	**7072**	**7415**	**7687**	**8182**	**8469**	**8677**	**8921**	**9133**	**1.3**	**1.0**	**0.6**	**0.5**
Public road transport	526	545	563	598	627	645	662	683	690	689	0.9	0.8	0.6	0.1
Private cars	4309	4472	4821	4944	4999	5282	5413	5482	5637	5762	1.0	0.7	0.4	0.5
2wheelers	150	155	166	176	184	194	199	203	207	212	1.3	1.0	0.5	0.4
Passenger light duty vehicles	227	239	259	270	278	296	304	310	316	321	1.2	0.9	0.4	0.4
Rail	461	482	524	567	614	646	685	728	765	791	1.6	1.3	1.2	0.8
Aviation	527	577	700	819	940	1074	1158	1222	1255	1306	3.6	2.7	1.3	0.7
Inland navigation	40	41	40	42	44	45	47	49	51	52	0.3	0.8	0.8	0.7
Freight transport activity (Gtkm)	**2495**	**2664**	**2885**	**3070**	**3226**	**3373**	**3484**	**3589**	**3651**	**3667**	**1.4**	**0.9**	**0.6**	**0.2**
Heavy duty vehicles	1740	1880	2016	2135	2235	2330	2397	2463	2491	2473	1.3	0.9	0.6	0.0
Freight light duty vehicles	60	61	64	65	70	76	80	83	85	87	0.5	1.7	0.9	0.5
Rail	414	440	503	550	582	612	638	663	684	708	2.2	1.1	0.8	0.7
Inland waterway navigation	280	282	303	321	339	355	369	380	390	399	1.3	1.0	0.7	0.5
Final Energy Demand (ktoe)	**362402**	**372948**	**383850**	**369104**	**340624**	**323908**	**293347**	**263279**	**242774**	**228128**	**-0.1**	**-1.3**	**-2.1**	**-1.4**
by transport mode														
Passenger transport	**254276**	**258834**	**265305**	**251298**	**230033**	**217764**	**190651**	**163216**	**146011**	**136704**	**-0.3**	**-1.4**	**-2.8**	**-1.8**
Public road transport	5028	5201	5182	5073	4656	4206	3875	3664	3474	3290	-0.3	-1.9	-1.4	-1.1
Private cars	169568	170739	169825	152830	131247	120303	98382	74359	61462	54830	-1.1	-2.4	-4.7	-3.0
2wheelers	7094	7191	7386	7242	6854	6295	5159	4004	2908	2206	0.1	-1.4	-4.4	-5.8
Passenger light duty vehicles	18828	19761	20139	18131	15854	14365	12190	10812	9882	9241	-0.9	-2.3	-2.8	-1.6
Rail	1960	1985	2130	2192	2291	2258	2249	2207	2118	2055	1.0	0.3	-0.2	-0.7
Aviation	49703	51804	58590	63682	66899	68048	66472	65763	63690	62588	2.1	0.7	-0.3	-0.5
Inland navigation	2094	2153	2053	2148	2233	2289	2324	2407	2477	2494	0.0	0.6	0.5	0.4
Freight transport	**108126**	**114114**	**118546**	**117806**	**110591**	**106144**	**102696**	**100064**	**96763**	**91423**	**0.3**	**-1.0**	**-0.6**	**-0.9**
Heavy duty vehicles	92279	98249	101999	101943	94691	90465	87115	84744	81710	76717	0.4	-1.2	-0.7	-1.0
Freight light duty vehicles	5079	5174	5054	4456	4135	3820	3329	3047	2816	2634	-1.5	-1.5	-2.2	-1.4
Rail	7476	7383	8010	7690	7787	7670	7906	7789	7665	7464	0.4	0.0	0.2	-0.4
Inland waterway navigation	3292	3308	3483	3717	3978	4189	4346	4484	4572	4608	1.2	1.2	0.7	0.3
by fuel														
Oil products	**352414**	**353460**	**355806**	**325703**	**289543**	**259902**	**221038**	**175924**	**134707**	**106415**	**-0.8**	**-2.2**	**-3.8**	**-4.9**
Gasoline	114297	106549	101683	85283	69245	56854	40752	25943	17354	13047	-2.2	-4.0	-7.5	-6.6
Diesel	182919	188875	185560	163495	138340	118238	101189	80320	62119	45211	-1.4	-3.2	-3.8	-5.6
Kerosene	49703	51804	58590	63682	66899	67659	64325	58142	45256	37773	2.1	0.6	-1.5	-4.2
Liquefied Petroleum Gas	4520	5315	9131	12445	14304	16450	14148	10995	9553	9972	8.9	2.8	-3.9	-1.0
Residual fuel oil	974	916	843	797	756	701	623	524	425	412	-1.4	-1.3	-2.9	-2.4
Biofuels	**3129**	**11986**	**18237**	**29019**	**31474**	**36536**	**38111**	**47073**	**62894**	**72812**	**9.2**	**2.3**	**2.6**	**4.5**
Bio Gasoline	581	3338	5102	7902	7922	8918	8957	8524	7803	6693	9.0	1.2	-0.5	-2.4
Bio Diesel	2548	8648	13135	21116	23548	26790	26329	29908	34701	37345	9.3	2.4	1.1	2.2
Bio Kerosene	0	0	0	0	0	389	2146	7621	18434	24815			34.6	12.5
DME	0	0	0	0	4	354	536	785	1567	3325	9.3	95.1	8.3	15.5
Bio Heavy	0	0	0	0	0	8	43	106	187	199			29.7	6.4
Biogas	0	0	0	0	0	76	100	129	202	436	42.8	121.7	5.4	12.9
Electricity	6353	6780	7702	9832	12377	15826	21741	26952	30153	32295	**3.8**	**4.9**	**5.5**	**1.8**
Natural Gas	506	723	2105	4405	6813	10746	10494	9117	8637	7744	**19.8**	**9.3**	**-1.6**	**-1.6**
Hydrogen	0	0	0	144	418	899	1962	4212	6383	8861		**20.1**	**16.7**	**7.7**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.5**	**33.9**	**29.9**	**26.6**	**22.5**	**18.8**	**16.4**	**15.0**	**-1.6**	**-2.4**	**-3.4**	**-2.3**
Public road transport	9.6	9.5	9.2	8.5	7.4	6.5	5.9	5.4	5.0	4.8	-1.2	-2.6	-1.9	-1.2
Private cars	39.4	38.2	35.2	30.9	26.3	22.8	18.2	13.6	10.9	9.5	-2.1	-3.0	-5.0	-3.5
2wheelers	47.3	46.4	44.5	41.2	37.2	32.5	25.9	19.7	14.0	10.4	-1.2	-2.4	-4.9	-6.2
Passenger light duty vehicles	82.8	82.7	77.9	67.2	57.1	48.5	40.1	34.9	31.3	28.8	-2.1	-3.2	-3.2	-1.9
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.1	63.4	57.4	53.8	50.7	47.9	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.5	49.7	49.2	48.6	47.8	-0.3	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**41.1**	**38.4**	**34.3**	**31.5**	**29.5**	**27.9**	**26.5**	**24.9**	**-1.1**	**-2.0**	**-1.2**	**-1.1**
Heavy duty vehicles	53.0	52.3	50.6	47.7	42.4	38.8	36.3	34.4	32.8	31.0	-0.9	-2.0	-1.2	-1.0
Freight light duty vehicles	84.8	84.4	79.5	69.0	59.1	50.2	41.7	36.6	33.0	30.2	-2.0	-3.1	-3.1	-1.9
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.8	11.2	10.5	-1.8	-1.1	-0.6	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	-0.1	0.2	0.0	-0.2
CO_2 EMISSIONS (in ktons CO_2)	**1053078**	**1057732**	**1066661**	**980848**	**877571**	**797314**	**682059**	**545339**	**421377**	**333873**	**-0.8**	**-2.1**	**-3.7**	**-4.8**
Passenger transport	740076	737534	742879	675467	603947	550057	453178	343214	252779	203830	-0.9	-2.0	-4.6	-5.1
Public road transport	15225	15250	14811	13908	12308	10442	8722	7348	6173	4719	-0.9	-2.8	-3.5	-4.3
Private cars	493354	483790	470538	399197	328988	283255	209090	128442	84923	64059	-1.9	-3.4	-7.6	-6.7
2wheelers	20311	20133	20333	19230	17955	15411	11766	7993	4759	2969	-0.5	-2.2	-6.4	-9.4
Passenger light duty vehicles	56340	57217	56393	47103	38984	33042	25986	20812	17486	15230	-1.9	-3.5	-4.5	-3.1
Rail	1085	967	814	649	532	398	267	140	48	4	-3.9	-4.8	-9.9	-29.5
Aviation	147321	153547	173660	188755	198287	200541	190661	172332	134139	111961	2.1	0.6	-1.5	-4.2
Inland navigation	6439	6631	6330	6625	6893	6967	6687	6148	5252	4888	0.0	0.5	-1.2	-2.3
Freight transport	313002	320197	323782	305381	273624	247257	228880	202125	168598	130043	**-0.5**	**-2.1**	**-2.0**	**-4.3**
Heavy duty vehicles	279315	288093	291926	277253	247259	222881	207112	183440	153239	116450	-0.4	-2.2	-1.9	-4.4
Freight light duty vehicles	15142	14919	14106	11589	10199	8816	7146	5939	5057	4406	-2.5	-2.7	-3.9	-2.9
Rail	8377	6977	7010	5085	3917	2866	2218	1471	822	383	-3.1	-5.6	-6.4	-12.6
Inland waterway navigation	10168	10209	10740	11454	12250	12694	12405	11275	9481	8803	1.2	1.0	-1.2	-2.4

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B)										EU27: Renew battery success with CO2 standards				
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260691**	**277070**	**284111**	**277069**	**295541**	**304258**	**307943**	**316617**	**324648**	**0.9**	**0.4**	**0.4**	**0.5**
Diesel Conventional	87565	101857	104991	85450	57211	42051	26769	14276	8135	5904	-1.7	-6.8	-10.2	-8.5
Diesel Hybrid	0	204	2259	11767	22652	26376	21747	14650	10514	8607	50.0	8.4	-5.7	-5.2
Diesel plug-in hybrid	0	0	750	8425	15499	22794	35088	38112	37860	35672		10.5	5.3	-0.7
Gasoline Conventional	150450	149264	150464	127532	90915	67391	41333	20289	10188	6753	-1.6	-6.2	-11.3	-10.4
Gasoline Hybrid	24	221	2407	15268	31060	39532	34139	24195	17797	14673	52.8	10.0	-4.8	-4.9
Gasoline plug-in hybrid	0	0	711	10066	20025	30408	48691	59869	60321	55162		11.7	7.0	-0.8
LPG	4849	8146	12996	17249	19223	22400	19793	14298	10761	9608	7.8	2.6	-4.4	-3.9
CNG	718	994	2471	5260	8485	12264	11707	8592	6407	5377	18.1	8.8	-3.5	-4.6
E85	0	6	17	97	496	1119	1402	1296	1164	1061	32.2	27.7	1.5	-2.0
Electric	0	0	4	2516	9942	27765	56310	96346	128656	149287		27.1	13.2	4.5
Hydrogen	0	0	0	483	1562	3440	7280	16020	24814	32545		21.7	16.6	7.3
2wheelers	**31568**	**33226**	**36237**	**38927**	**41410**	**43814**	**45189**	**45981**	**46825**	**47824**	**1.6**	**1.2**	**0.5**	**0.4**
Gasoline	31568	33226	36237	37201	38008	35908	30447	23044	15640	10721	1.1	-0.4	-4.3	-7.4
Electricity	0	0	0	1726	3402	7907	14742	22937	31186	37103		16.4	11.2	4.9
HDVs, buses and coaches	**8580**	**9479**	**10156**	**10636**	**11005**	**11637**	**12064**	**12427**	**12592**	**12589**	**1.2**	**0.9**	**0.7**	**0.1**
Diesel Conventional	8565	9457	10031	10075	8305	7046	5870	5165	4847	4389	0.6	-3.5	-3.1	-1.6
Diesel Hybrid	0	6	69	422	2435	3989	5229	5846	5803	5590	54.0	25.2	3.9	-0.4
LPG	2	2	12	34	68	117	177	280	416	584	34.1	13.3	9.1	7.6
CNG	13	15	44	78	124	252	376	509	657	763	18.2	12.5	7.3	4.1
Electric	0	0	0	25	67	213	372	546	730	1013		23.8	9.9	6.4
Hydrogen	0	0	0	2	6	19	41	80	138	248		23.7	15.6	12.0
Total annual cost excl. disutility (in million Euro'08)	**2421017**	**2603767**	**2804902**	**3060886**	**3287813**	**3470021**	**3663543**	**3871162**	**4059869**	**4186932**	**1.6**	**1.3**	**1.1**	**0.8**
Passenger transport	**1993282**	**2130980**	**2262697**	**2465940**	**2651199**	**2805073**	**2966559**	**3143410**	**3300941**	**3392561**	**1.5**	**1.3**	**1.1**	**0.8**
Public road transport	47158	52717	56138	60175	64907	65888	67812	69920	71651	72785	1.3	0.9	0.6	0.4
Private cars	1590459	1692401	1771772	1913214	2042646	2151985	2273545	2408528	2513276	2556694	1.2	1.2	1.1	0.6
2wheelers	46744	48913	52916	59410	66632	69136	73750	78036	82975	85551	2.0	1.5	1.2	0.9
Passenger light duty vehicles	113667	124429	135287	143393	148184	154859	162062	167752	174494	179877	1.4	0.8	0.8	0.7
Rail	74543	78188	81211	84097	87468	88385	89453	92658	96441	98600	0.7	0.5	0.5	0.6
Aviation	112942	126147	156464	195900	231031	264271	288995	315057	349923	386126	4.5	3.0	1.8	2.1
Inland navigation	7770	8185	8908	9750	10331	10550	10942	11459	12181	12927	1.8	0.8	0.8	1.2
Freight transport	**427736**	**472786**	**542206**	**594946**	**636614**	**664948**	**696984**	**727752**	**758928**	**794372**	**2.3**	**1.1**	**0.9**	**0.9**
Heavy duty vehicles	298800	338403	392572	433279	465491	486638	513236	538691	565239	594977	2.5	1.2	1.0	1.0
Freight light duty vehicles	31420	33154	34518	35581	38929	41575	44486	47500	49902	51549	0.7	1.6	1.3	0.8
Rail	55914	58699	67840	75044	77776	79835	79949	80147	79907	81082	2.5	0.6	0.0	0.1
Inland waterway navigation	41602	42531	47276	51043	54418	56901	59312	61414	63879	66764	1.8	1.1	0.8	0.8
External costs (in million Euro'08) (1)	**447714**	**404182**	**409346**	**415989**	**431657**	**446804**	**446329**	**442928**	**444614**	**446314**	**0.3**	**0.7**	**-0.1**	**0.1**
Disutility costs (in million Euro'08)	**0**	**111**	**31938**	**55905**	**108545**	**81189**	**104289**	**132079**	**146030**	**157734**	**86.3**	**3.8**	**5.0**	**1.8**
Passenger transport	0	96	14022	39861	87568	60447	77755	101075	104390	98996	82.6	4.3	5.3	-0.2
Freight transport	0	14	17916	16044	20977	20741	26534	31004	41640	58739	101.8	2.6	4.1	6.6
Total costs (incl. disutility and external costs)	**2421017**	**2603877**	**2836841**	**3116791**	**3396358**	**3551210**	**3767831**	**4003241**	**4205899**	**4344667**	**1.8**	**1.3**	**1.2**	**0.8**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: Renew battery success with energy efficiency standards												SUMMARY (A)	
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6511**	**7072**	**7419**	**7660**	**8166**	**8495**	**8777**	**9017**	**9239**	**1.3**	**1.0**	**0.7**	**0.5**
Public road transport	526	545	563	589	614	639	651	663	667	664	0.8	0.8	0.4	0.0
Private cars	4309	4472	4821	4956	4985	5271	5446	5593	5744	5880	1.0	0.6	0.6	0.5
2wheelers	150	155	166	177	185	195	203	205	208	211	1.3	1.0	0.5	0.3
Passenger light duty vehicles	227	239	259	270	277	295	305	316	324	332	1.2	0.9	0.7	0.5
Rail	461	482	524	566	614	648	684	722	759	783	1.6	1.3	1.1	0.8
Aviation	527	577	700	819	940	1073	1160	1230	1263	1316	3.6	2.7	1.4	0.7
Inland navigation	40	41	40	42	44	45	47	49	51	52	0.3	0.8	0.7	0.6
Freight transport activity (Gtkm)	**2495**	**2664**	**2886**	**3070**	**3225**	**3372**	**3485**	**3591**	**3651**	**3666**	**1.4**	**0.9**	**0.6**	**0.2**
Heavy duty vehicles	1740	1880	2016	2135	2234	2329	2399	2464	2490	2470	1.3	0.9	0.6	0.0
Freight light duty vehicles	60	61	64	65	70	76	80	83	86	88	0.5	1.7	0.9	0.5
Rail	414	440	503	550	582	612	638	663	684	709	2.2	1.1	0.8	0.7
Inland waterway navigation	280	282	303	321	339	355	369	381	390	399	1.3	1.0	0.7	0.5
Final Energy Demand (ktoe)	**362402**	**372948**	**383541**	**369317**	**339001**	**322318**	**294994**	**268024**	**244141**	**225984**	**-0.1**	**-1.4**	**-1.8**	**-1.7**
by transport mode														
Passenger transport	**254276**	**258834**	**265305**	**252147**	**228735**	**216342**	**192786**	**168728**	**148655**	**136363**	**-0.3**	**-1.5**	**-2.5**	**-2.1**
Public road transport	5028	5201	5182	4815	4301	3918	3548	3265	2983	2761	-0.8	-2.0	-1.8	-1.7
Private cars	169568	170739	169825	153793	130138	118763	99484	78852	64432	56036	-1.0	-2.6	-4.0	-3.4
2wheelers	7094	7191	7386	7362	7043	6794	6374	5126	3686	2358	0.2	-0.8	-2.8	-7.5
Passenger light duty vehicles	18828	19761	20139	18133	15813	14287	12248	10694	8829	7530	-0.9	-2.4	-2.9	-3.4
Rail	1960	1985	2130	2191	2291	2262	2247	2192	2102	2037	1.0	0.3	-0.3	-0.7
Aviation	49703	51804	58590	63700	66905	68022	66558	66196	64151	63155	2.1	0.7	-0.3	-0.5
Inland navigation	2094	2153	2053	2153	2243	2295	2329	2402	2472	2486	0.0	0.6	0.5	0.3
Freight transport	**108126**	**114114**	**118237**	**117170**	**110266**	**105977**	**102207**	**99296**	**95486**	**89621**	**0.3**	**-1.0**	**-0.6**	**-1.0**
Heavy duty vehicles	92279	98249	101690	101308	94363	90297	86631	84081	80812	75486	0.3	-1.1	-0.7	-1.1
Freight light duty vehicles	5079	5174	5054	4452	4135	3819	3325	2940	2431	2052	-1.5	-1.5	-2.6	-3.5
Rail	7476	7383	8010	7692	7789	7671	7905	7790	7670	7472	0.4	0.0	0.2	-0.4
Inland waterway navigation	3292	3308	3483	3717	3978	4189	4346	4485	4573	4610	1.2	1.2	0.7	0.3
by fuel														
Oil products	**352414**	**353460**	**355520**	**325965**	**286615**	**257131**	**223045**	**181973**	**137255**	**103548**	**-0.8**	**-2.3**	**-3.4**	**-5.5**
Gasoline	114297	106549	101682	86093	68685	56480	44530	30987	21652	15815	-2.1	-4.1	-5.8	-6.5
Diesel	182919	188875	185275	162874	136633	117249	103055	85565	65267	46028	-1.5	-3.2	-3.1	-6.0
Kerosene	49703	51804	58590	63700	66905	67633	64409	58526	45586	36799	2.1	0.6	-1.4	-4.5
Liquefied Petroleum Gas	4520	5315	9130	12501	13636	15067	10428	6372	4328	4496	8.9	1.9	-8.2	-3.4
Residual fuel oil	974	916	843	797	757	701	624	523	424	411	-1.4	-1.3	-2.9	-2.4
Biofuels	**3129**	**11986**	**18216**	**28960**	**32841**	**38345**	**41690**	**51649**	**68000**	**79614**	**9.2**	**2.8**	**3.0**	**4.4**
Bio Gasoline	581	3338	5102	7958	8214	9258	9821	10583	9312	7635	9.1	1.5	1.3	-3.2
Bio Diesel	2548	8648	13113	21001	24623	28266	29061	32406	38228	41810	9.3	3.0	1.4	2.6
Bio Kerosene	0	0	0	0	0	389	2149	7671	18566	26356			34.7	13.1
DME	0	0	0	0	4	354	541	801	1591	3374	9.2	95.2	8.5	15.5
Bio Heavy	0	0	0	0	0	8	43	106	187	198			29.7	6.4
Biogas	0	0	0	0	0	70	74	82	117	241	42.5	120.4	1.6	11.4
Electricity	6353	6780	7702	9946	12631	16028	20742	26426	31413	35370	**3.9**	**4.9**	**5.1**	**3.0**
Natural Gas	506	723	2104	4275	6462	9897	7949	6039	5197	4422	**19.5**	**8.8**	**-4.8**	**-3.1**
Hydrogen	0	0	0	170	452	917	1567	1936	2276	3030		**18.4**	**7.8**	**4.6**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.5**	**34.0**	**29.9**	**26.5**	**22.7**	**19.2**	**16.5**	**14.8**	**-1.6**	**-2.5**	**-3.2**	**-2.6**
Public road transport	9.6	9.5	9.2	8.2	7.0	6.1	5.5	4.9	4.5	4.2	-1.5	-2.8	-2.2	-1.7
Private cars	39.4	38.2	35.2	31.0	26.1	22.5	18.3	14.1	11.2	9.5	-2.1	-3.1	-4.6	-3.8
2wheelers	47.3	46.4	44.5	41.7	38.1	34.8	31.4	25.0	17.8	11.2	-1.1	-1.8	-3.3	-7.7
Passenger light duty vehicles	82.8	82.7	77.9	67.1	57.1	48.5	40.1	33.9	27.2	22.7	-2.1	-3.2	-3.5	-3.9
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.2	63.4	57.4	53.8	50.8	48.0	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.4	49.7	49.3	48.6	47.8	-0.3	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**41.0**	**38.2**	**34.2**	**31.4**	**29.3**	**27.7**	**26.2**	**24.4**	**-1.1**	**-1.9**	**-1.3**	**-1.2**
Heavy duty vehicles	53.0	52.3	50.4	47.5	42.2	38.8	36.1	34.1	32.5	30.6	-1.0	-2.0	-1.3	-1.1
Freight light duty vehicles	84.8	84.4	79.5	69.0	59.2	50.2	41.7	35.3	28.3	23.3	-2.0	-3.1	-3.5	-4.1
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.7	11.2	10.5	-1.8	-1.1	-0.6	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	-0.1	0.2	0.0	-0.2
CO_2 EMISSIONS (in ktons CO_2)	**1053078**	**1057732**	**1065780**	**981163**	**868184**	**787522**	**683253**	**557752**	**422551**	**319210**	**-0.7**	**-2.2**	**-3.4**	**-5.4**
Passenger transport	740076	737534	742879	678358	598307	543887	459812	357856	262039	202714	-0.8	-2.2	-4.1	-5.5
Public road transport	15225	15250	14811	12991	11098	9366	7613	6048	4621	3177	-1.6	-3.2	-4.3	-6.2
Private cars	493354	483790	470538	402491	324184	277185	213161	140988	95912	71573	-1.8	-3.7	-6.5	-6.6
2wheelers	20311	20133	20333	19574	18504	16728	15047	10811	6544	3291	-0.3	-1.6	-4.3	-11.2
Passenger light duty vehicles	56340	57217	56392	47204	38762	32760	26115	20262	14557	10723	-1.9	-3.6	-4.7	-6.2
Rail	1085	967	814	649	532	398	267	140	48	4	-3.9	-4.8	-9.9	-29.5
Aviation	147321	153547	173660	188807	198305	200465	190908	173470	135115	109072	2.1	0.6	-1.4	-4.5
Inland navigation	6439	6631	6330	6641	6922	6985	6701	6137	5241	4873	0.0	0.5	-1.3	-2.3
Freight transport	313002	320197	322901	302806	269877	243635	223441	199896	160512	116496	**-0.6**	**-2.2**	**-2.0**	**-5.3**
Heavy duty vehicles	279315	288093	291047	274671	243544	219283	201686	181524	146167	104380	-0.5	-2.2	-1.9	-5.4
Freight light duty vehicles	15142	14919	14104	11594	10166	8791	7132	5624	4039	2926	-2.5	-2.7	-4.4	-6.3
Rail	8377	6977	7010	5086	3917	2867	2219	1472	822	383	-3.1	-5.6	-6.5	-12.6
Inland waterway navigation	10168	10209	10740	11454	12250	12694	12405	11277	9483	8807	1.2	1.0	-1.2	-2.4

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B)										EU27: Renew battery success with energy efficiency standards				
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**'10-'20**	**'20-'30**	**'30-'40**	**'40-'50**
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260691**	**277070**	**284565**	**276503**	**294494**	**305503**	**314069**	**323274**	**332182**	**0.9**	**0.3**	**0.6**	**0.6**
Diesel Conventional	87565	101857	104991	86353	56610	40522	21763	7990	1898	675	-1.6	-7.3	-15.0	-21.9
Diesel Hybrid	0	204	2259	11417	23420	29602	36983	34676	26784	19287	49.5	10.0	1.6	-5.7
Diesel plug-in hybrid	0	0	750	7835	15718	22720	33102	45805	54260	57603		11.2	7.3	2.3
Gasoline Conventional	150450	149264	150464	129286	89293	63915	33524	11833	2391	690	-1.4	-6.8	-15.5	-24.7
Gasoline Hybrid	24	221	2407	14653	32140	41853	51818	48785	37949	26765	52.1	11.1	1.5	-5.8
Gasoline plug-in hybrid	0	0	711	9546	20568	31238	45038	59207	67093	69095		12.6	6.6	1.6
LPG	4849	8146	12996	17359	18302	20359	14698	7568	3065	1624	7.9	1.6	-9.4	-14.3
CNG	718	994	2471	5123	7999	11073	8459	4388	1700	782	17.8	8.0	-8.8	-15.8
E85	0	6	17	91	504	1076	1538	1168	671	315	31.4	28.1	0.8	-12.3
Electric	0	0	4	2446	10333	28674	52799	85771	120551	148610		27.9	11.6	5.7
Hydrogen	0	0	0	457	1615	3461	5781	6878	6911	6737		22.4	7.1	-0.2
2wheelers	**31568**	**33226**	**36237**	**39151**	**41631**	**44278**	**46263**	**46615**	**46909**	**47477**	**1.7**	**1.2**	**0.5**	**0.2**
Gasoline	31568	33226	36237	38053	39439	39869	39777	31844	21288	10719	1.4	0.5	-2.2	-10.3
Electricity	0	0	0	1098	2191	4410	6486	14771	25622	36758		14.9	12.8	9.5
HDVs, buses and coaches	**8580**	**9479**	**10157**	**10621**	**10980**	**11623**	**12042**	**12392**	**12545**	**12533**	**1.1**	**0.9**	**0.6**	**0.1**
Diesel Conventional	8565	9457	9967	9830	7990	6789	5584	4853	4483	3956	0.4	-3.6	-3.3	-2.0
Diesel Hybrid	0	6	134	609	2692	4208	5485	6133	6134	6013	59.8	21.3	3.8	-0.2
LPG	2	2	12	28	55	103	151	238	348	481	31.8	13.8	8.8	7.3
CNG	13	15	44	55	76	200	297	407	525	591	14.2	13.7	7.4	3.8
Electric	0	0	0	93	156	302	479	672	900	1223		12.5	8.3	6.2
Hydrogen	0	0	0	6	11	23	46	88	153	269		13.9	14.5	11.8
Total annual cost excl. disutility (in million Euro'08)	**2421017**	**2603767**	**2804782**	**3059914**	**3289671**	**3474232**	**3662267**	**3831049**	**3987608**	**4115772**	**1.6**	**1.3**	**1.0**	**0.7**
<u>Passenger transport</u>	**1993282**	**2130980**	**2262696**	**2465122**	**2653106**	**2809279**	**2965408**	**3103512**	**3228636**	**3320839**	**1.5**	**1.3**	**1.0**	**0.7**
Public road transport	47158	52717	56138	60149	64941	65838	67339	68732	70324	71247	1.3	0.9	0.4	0.4
Private cars	1590459	1692401	1771771	1912702	2045615	2158048	2274435	2367330	2436913	2479053	1.2	1.2	0.9	0.5
2wheelers	46744	48913	52916	59079	65797	67965	71348	76004	82373	86591	1.9	1.4	1.1	1.3
Passenger light duty vehicles	113667	124429	135287	143467	147791	154157	162559	170952	178781	184661	1.4	0.7	1.0	0.8
Rail	74543	78188	81211	84004	87594	88579	89398	91868	95658	97662	0.7	0.5	0.4	0.6
Aviation	112942	126147	156464	195946	230989	264111	289362	317201	352445	388750	4.5	3.0	1.8	2.1
Inland navigation	7770	8185	8908	9775	10380	10582	10966	11424	12140	12874	1.8	0.8	0.8	1.2
<u>Freight transport</u>	**427736**	**472786**	**542086**	**594792**	**636565**	**664953**	**696859**	**727538**	**758972**	**794933**	**2.3**	**1.1**	**0.9**	**0.9**
Heavy duty vehicles	298800	338403	392456	433112	465413	486634	513172	538577	565277	595474	2.5	1.2	1.0	1.0
Freight light duty vehicles	31420	33154	34516	35566	38927	41581	44439	47362	49831	51496	0.7	1.6	1.3	0.8
Rail	55914	58699	67839	75066	77799	79836	79941	80176	79969	81161	2.5	0.6	0.0	0.1
Inland waterway navigation	41602	42531	47275	51048	54425	56902	59307	61422	63895	66802	1.8	1.1	0.8	0.8
External costs (in million Euro'08) (1)	**447714**	**404182**	**409219**	**415552**	**429841**	**445814**	**449269**	**453086**	**454828**	**455098**	**0.3**	**0.7**	**0.2**	**0.0**
Disutility costs (in million Euro'08)	**0**	**111**	**31827**	**54972**	**117326**	**86130**	**95321**	**102794**	**115679**	**124203**	**86.0**	**4.6**	**1.8**	**1.9**
<u>Passenger transport</u>	0	96	14023	38945	95896	65046	69475	73406	76092	67786	82.2	5.3	1.2	-0.8
<u>Freight transport</u>	0	14	17804	16027	21429	21084	25845	29388	39588	56417	101.8	2.8	3.4	6.7
Total costs (incl. disutility and external costs)	**2421017**	**2603877**	**2836609**	**3114886**	**3406996**	**3560362**	**3757587**	**3933843**	**4103287**	**4239975**	**1.8**	**1.3**	**1.0**	**0.8**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: Dominant biomass with CO2 standards														SUMMARY (A)
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6511**	**7073**	**7422**	**7688**	**8163**	**8467**	**8675**	**8840**	**8997**	**1.3**	**1.0**	**0.6**	**0.4**
Public road transport	526	545	563	598	625	634	651	673	688	695	0.9	0.6	0.6	0.3
Private cars	4309	4472	4822	4950	5002	5277	5426	5491	5563	5629	1.0	0.6	0.4	0.2
2wheelers	150	155	166	176	185	195	202	207	211	213	1.3	1.0	0.6	0.3
Passenger light duty vehicles	227	239	259	270	277	294	303	309	312	314	1.2	0.8	0.5	0.2
Rail	461	482	524	567	614	646	684	726	769	800	1.6	1.3	1.2	1.0
Aviation	527	577	700	819	940	1071	1155	1220	1247	1294	3.6	2.7	1.3	0.6
Inland navigation	40	41	40	42	44	45	47	49	51	52	0.2	0.8	0.7	0.7
Freight transport activity (Gtkm)	**2495**	**2664**	**2885**	**3073**	**3235**	**3382**	**3498**	**3611**	**3680**	**3705**	**1.4**	**1.0**	**0.7**	**0.3**
Heavy duty vehicles	1740	1880	2016	2139	2247	2343	2417	2494	2531	2526	1.3	0.9	0.6	0.1
Freight light duty vehicles	60	61	64	64	69	74	78	81	83	84	0.5	1.5	0.8	0.4
Rail	414	440	503	549	581	611	636	659	679	702	2.2	1.1	0.8	0.6
Inland waterway navigation	280	282	303	320	338	354	367	378	387	394	1.3	1.0	0.7	0.4
Final Energy Demand (ktoe)	**362402**	**372960**	**383981**	**371961**	**345177**	**331560**	**312231**	**291725**	**270015**	**251310**	**0.0**	**-1.1**	**-1.3**	**-1.5**
by transport mode														
Passenger transport	**254276**	**258846**	**265429**	**253767**	**234026**	**225762**	**211032**	**194427**	**177498**	**165121**	**-0.2**	**-1.2**	**-1.5**	**-1.6**
Public road transport	5028	5201	5184	5134	4770	4294	3937	3663	3417	3216	-0.1	-1.8	-1.6	-1.3
Private cars	169568	170749	169920	154364	133136	125890	114949	100368	87322	77802	-1.0	-2.0	-2.2	-2.5
2wheelers	7094	7192	7386	7367	7165	6900	6463	6063	5496	4933	0.2	-0.7	-1.3	-2.0
Passenger light duty vehicles	18828	19762	20166	18865	17552	16249	14784	14046	13293	12486	-0.5	-1.5	-1.4	-1.2
Rail	1960	1985	2130	2191	2291	2258	2247	2201	2130	2081	1.0	0.3	-0.3	-0.6
Aviation	49703	51804	58590	63701	66881	67877	66327	65691	63369	62114	2.1	0.6	-0.3	-0.6
Inland navigation	2094	2153	2053	2144	2232	2294	2324	2396	2470	2489	0.0	0.7	0.4	0.4
Freight transport	**108126**	**114114**	**118551**	**118194**	**111150**	**105799**	**101199**	**97299**	**92518**	**86189**	**0.4**	**-1.1**	**-0.8**	**-1.2**
Heavy duty vehicles	92279	98249	101999	102175	94891	89689	85061	81274	76703	70764	0.4	-1.3	-1.0	-1.4
Freight light duty vehicles	5079	5174	5060	4616	4516	4271	3924	3816	3664	3474	-1.1	-0.8	-1.1	-0.9
Rail	7476	7383	8010	7686	7774	7659	7886	7755	7621	7402	0.4	0.0	0.1	-0.5
Inland waterway navigation	3292	3308	3483	3717	3969	4179	4328	4454	4530	4549	1.2	1.2	0.6	0.2
by fuel														
Oil products	**352414**	**353487**	**355944**	**329046**	**294509**	**263758**	**231279**	**191326**	**143681**	**103760**	**-0.7**	**-2.2**	**-3.2**	**-5.9**
Gasoline	114297	106546	101742	87224	72703	63902	53045	39353	27702	20704	-2.0	-3.1	-4.7	-6.2
Diesel	182919	188835	185579	165117	140755	115862	96823	77372	56289	33304	-1.3	-3.5	-4.0	-8.1
Kerosene	49703	51804	58590	63701	66881	67481	64132	57851	44388	35220	2.1	0.6	-1.5	-4.8
Liquefied Petroleum Gas	4520	5385	9192	12208	13414	15811	16661	16241	14920	14232	8.5	2.6	0.3	-1.3
Residual fuel oil	974	916	843	797	755	701	618	510	383	300	-1.4	-1.3	-3.1	-5.2
Biofuels	**3129**	**11984**	**18242**	**29468**	**32822**	**45480**	**54596**	**70593**	**93098**	**111583**	**9.4**	**4.4**	**4.5**	**4.7**
Bio Gasoline	581	3338	5105	8106	8424	10715	13190	16781	19581	19629	9.3	2.8	4.6	1.6
Bio Diesel	2548	8646	13136	21357	24307	32460	36574	42460	49216	55790	9.5	4.3	2.7	2.8
Bio Kerosene	0	0	0	0	0	396	2195	7840	18981	26894			34.8	13.1
DME	0	0	1	4	52	1038	1500	2087	3773	7384	36.2	72.9	7.2	13.5
Bio Heavy	0	0	0	0	0	8	47	119	229	310			30.5	10.1
Biogas	0	0	0	1	39	863	1089	1306	1319	1578	106.0	96.3	4.2	1.9
Electricity	6353	6780	7678	9206	10972	12791	15297	18212	21014	23421	**3.1**	**3.3**	**3.6**	**2.5**
Natural Gas	506	710	2116	4240	6773	9168	10292	9982	9497	8638	**19.6**	**8.0**	**0.9**	**-1.4**
Hydrogen	0	0	0	0	100	364	768	1612	2725	3908		**105.1**	**16.1**	**9.3**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.5**	**34.2**	**30.4**	**27.7**	**24.9**	**22.4**	**20.1**	**18.4**	**-1.5**	**-2.1**	**-2.1**	**-2.0**
Public road transport	9.6	9.5	9.2	8.6	7.6	6.8	6.0	5.4	5.0	4.6	-1.0	-2.4	-2.2	-1.6
Private cars	39.4	38.2	35.2	31.2	26.6	23.9	21.2	18.3	15.7	13.8	-2.0	-2.6	-2.6	-2.8
2wheelers	47.3	46.4	44.5	41.9	38.7	35.4	32.0	29.3	26.1	23.1	-1.0	-1.7	-1.9	-2.3
Passenger light duty vehicles	82.8	82.7	78.0	69.9	63.3	55.4	48.7	45.5	42.6	39.8	-1.7	-2.3	-1.9	-1.3
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.1	63.4	57.4	53.8	50.8	48.0	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.5	49.7	49.2	48.5	47.7	-0.3	-0.2	-0.3	-0.3
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**41.1**	**38.5**	**34.4**	**31.3**	**28.9**	**26.9**	**25.1**	**23.3**	**-1.1**	**-2.0**	**-1.5**	**-1.5**
Heavy duty vehicles	53.0	52.3	50.6	47.8	42.2	38.3	35.2	32.6	30.3	28.0	-0.9	-2.2	-1.6	-1.5
Freight light duty vehicles	84.8	84.4	79.6	71.7	65.3	57.4	50.6	47.3	44.4	41.5	-1.6	-2.2	-1.9	-1.3
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.8	11.2	10.5	-1.8	-1.1	-0.6	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	-0.1	0.2	0.0	-0.2
CO_2 EMISSIONS (in ktons CO_2)	**1053078**	**1057753**	**1067072**	**990451**	**892492**	**804653**	**710104**	**590463**	**447433**	**325515**	**-0.7**	**-2.1**	**-3.0**	**-5.8**
Passenger transport	740076	737556	743272	683830	617047	561851	497224	409241	304378	234081	-0.8	-1.9	-3.1	-5.4
Public road transport	15225	15249	14816	14144	12756	10520	8795	7016	5288	3502	-0.7	-2.9	-4.0	-6.7
Private cars	493354	483807	470839	404588	335651	290162	245231	185214	130435	96127	-1.8	-3.3	-4.4	-6.3
2wheelers	20311	20134	20334	19599	18874	17052	15185	12754	10021	7743	-0.3	-1.4	-2.9	-4.9
Passenger light duty vehicles	56340	57220	56479	49424	44110	36767	31076	26739	22337	18680	-1.5	-2.9	-3.1	-3.5
Rail	1085	967	814	649	532	394	261	134	45	4	-3.9	-4.9	-10.2	-30.3
Aviation	147321	153548	173659	188811	198235	200014	190086	171469	131566	104393	2.1	0.6	-1.5	-4.8
Inland navigation	6439	6631	6330	6615	6889	6942	6590	5915	4685	3632	0.0	0.5	-1.6	-4.8
Freight transport	313002	320197	323800	306621	275445	242802	212880	181222	143055	91434	**-0.4**	**-2.3**	**-2.9**	**-6.6**
Heavy duty vehicles	279315	288093	291926	277981	247943	217617	190204	161632	127716	79517	-0.4	-2.4	-2.9	-6.8
Freight light duty vehicles	15142	14919	14124	12103	11369	9766	8359	7387	6299	5356	-2.1	-2.1	-2.8	-3.2
Rail	8377	6977	7010	5085	3911	2846	2170	1414	769	334	-3.1	-5.6	-6.8	-13.4
Inland waterway navigation	10168	10209	10740	11452	12222	12572	12147	10790	8271	6226	1.2	0.9	-1.5	-5.3

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B)										EU27: Dominant biomass with CO2 standards				
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260703**	**277089**	**284366**	**277254**	**294980**	**304547**	**308286**	**311676**	**315457**	**0.9**	**0.4**	**0.4**	**0.2**
Diesel Conventional	87565	101810	105046	86593	60227	47954	38676	29204	21204	16049	-1.6	-5.7	-4.8	-5.8
Diesel Hybrid	0	204	2266	12960	25060	30098	29701	26191	22034	18788	51.4	8.8	-1.4	-3.3
Diesel plug-in hybrid	0	0	625	7580	13749	18694	23246	32316	41500	46771		9.4	5.6	3.8
Gasoline Conventional	150450	149253	150584	129532	95794	80554	64455	46942	32183	23177	-1.4	-4.6	-5.3	-6.8
Gasoline Hybrid	24	221	2414	16852	34413	44339	49252	45676	39323	33315	54.3	10.2	0.3	-3.1
Gasoline plug-in hybrid	0	0	579	8651	17034	25562	32589	45702	60859	71351		11.4	6.0	4.6
LPG	4849	8234	13080	16946	18446	22254	24243	23862	21932	21034	7.5	2.8	0.7	-1.3
CNG	718	976	2476	5024	8602	12933	15611	16187	15860	15442	17.8	9.9	2.3	-0.5
E85	0	6	17	111	675	2165	4201	5286	5722	5847	34.1	34.6	9.3	1.0
Electric	0	0	3	116	2873	9196	20213	32253	42876	51575		54.9	13.4	4.8
Hydrogen	0	0	0	1	380	1231	2361	4666	8183	12107		103.6	14.3	10.0
2wheelers	**31568**	**33227**	**36239**	**38998**	**41649**	**44137**	**46012**	**47290**	**48086**	**48650**	**1.6**	**1.2**	**0.7**	**0.3**
Gasoline	31568	33227	36239	37897	39939	40386	40173	38982	36302	33447	1.3	0.6	-0.4	-1.5
Electricity	0	0	0	1101	1710	3751	5839	8309	11784	15204		13.0	8.3	6.2
HDVs, buses and coaches	**8580**	**9479**	**10156**	**10645**	**11036**	**11659**	**12096**	**12488**	**12693**	**12757**	**1.2**	**0.9**	**0.7**	**0.2**
Diesel Conventional	8565	9457	10032	10105	8371	7157	6034	5399	5163	4830	0.7	-3.4	-2.8	-1.1
Diesel Hybrid	0	6	68	422	2453	4017	5296	6001	6085	6065	54.1	25.3	4.1	0.1
LPG	2	2	12	40	82	156	231	323	419	507	36.3	14.7	7.5	4.6
CNG	13	15	44	78	118	185	238	288	338	378	18.3	9.0	4.5	2.8
Electric	0	0	0	0	12	131	267	407	553	749		79.4	12.0	6.3
Hydrogen	0	0	0	0	0	12	31	71	134	227		120.9	19.6	12.3
Total annual cost excl. disutility (in million Euro'08)	**2421021**	**2603713**	**2804815**	**3059607**	**3290228**	**3479812**	**3652124**	**3817271**	**3988112**	**4141593**	**1.6**	**1.3**	**0.9**	**0.8**
Passenger transport	**1993286**	**2130926**	**2262609**	**2465143**	**2655388**	**2816987**	**2958669**	**3094911**	**3236489**	**3356958**	**1.5**	**1.3**	**0.9**	**0.8**
Public road transport	47158	52715	56136	60132	64903	66180	67963	69996	71953	73374	1.3	1.0	0.6	0.5
Private cars	1590463	1692338	1771660	1911867	2045048	2159695	2260548	2355331	2446062	2520158	1.2	1.2	0.9	0.7
2wheelers	46744	48915	52919	59407	66353	69349	72764	75534	78984	80889	2.0	1.6	0.9	0.7
Passenger light duty vehicles	113667	124439	135312	143937	150306	159215	168909	175652	182621	188184	1.5	1.0	1.0	0.7
Rail	74543	78186	81210	84079	87451	88405	89217	92386	96989	99913	0.7	0.5	0.4	0.8
Aviation	112942	126148	156465	195986	231005	263561	288321	314601	347712	381504	4.5	3.0	1.8	1.9
Inland navigation	7770	8185	8907	9735	10323	10580	10948	11409	12168	12938	1.7	0.8	0.8	1.3
Freight transport	**427736**	**472787**	**542206**	**594464**	**634839**	**662825**	**693455**	**722360**	**751623**	**784635**	**2.3**	**1.1**	**0.9**	**0.8**
Heavy duty vehicles	298800	338403	392571	432884	463844	484232	509495	533406	558016	585329	2.5	1.1	1.0	0.9
Freight light duty vehicles	31420	33154	34519	35602	39104	42159	45187	48231	50932	53036	0.7	1.7	1.4	1.0
Rail	55914	58699	67840	74975	77617	79667	79714	79740	79373	80350	2.5	0.6	0.0	0.1
Inland waterway navigation	41602	42531	47276	51003	54274	56767	59060	60983	63302	65920	1.8	1.1	0.7	0.8
External costs (in million Euro'08) (1)	**447714**	**404189**	**409395**	**417649**	**434268**	**450591**	**456676**	**463065**	**466110**	**465891**	**0.3**	**0.8**	**0.3**	**0.1**
Disutility costs (in million Euro'08)	**0**	**84**	**31852**	**53055**	**106112**	**81796**	**95935**	**124834**	**161604**	**187545**	**90.5**	**4.4**	**4.3**	**4.2**
Passenger transport	0	75	13937	37704	87108	62727	72481	98599	126107	136847	86.2	5.2	4.6	3.3
Freight transport	0	9	17915	15351	19004	19068	23454	26235	35497	50698	110.5	2.2	3.2	6.8
Total costs (incl. disutility and external costs)	**2421021**	**2603798**	**2836666**	**3112663**	**3396339**	**3561607**	**3748059**	**3942105**	**4149716**	**4329138**	**1.8**	**1.4**	**1.0**	**0.9**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: Dominant biomass with energy efficiency standards **SUMMARY (A)**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6511**	**7073**	**7434**	**7678**	**8137**	**8459**	**8715**	**8887**	**9028**	**1.3**	**0.9**	**0.7**	**0.4**
Public road transport	526	545	563	591	613	624	643	666	683	693	0.8	0.5	0.6	0.4
Private cars	4309	4472	4822	4968	5003	5263	5427	5538	5613	5662	1.1	0.6	0.5	0.2
2wheelers	150	155	166	178	186	195	202	207	212	214	1.4	0.9	0.6	0.3
Passenger light duty vehicles	227	239	259	270	277	293	303	309	313	314	1.2	0.8	0.6	0.1
Rail	461	482	524	566	613	647	684	724	767	799	1.6	1.3	1.1	1.0
Aviation	527	577	700	820	941	1071	1155	1222	1249	1294	3.6	2.7	1.3	0.6
Inland navigation	40	41	40	42	44	46	47	49	51	52	0.3	0.9	0.7	0.7
Freight transport activity (Gtkm)	**2495**	**2664**	**2886**	**3074**	**3235**	**3382**	**3498**	**3612**	**3680**	**3705**	**1.4**	**1.0**	**0.7**	**0.3**
Heavy duty vehicles	1740	1880	2016	2140	2246	2343	2418	2494	2531	2526	1.3	0.9	0.6	0.1
Freight light duty vehicles	60	61	64	64	69	74	78	81	83	84	0.5	1.5	0.8	0.4
Rail	414	440	503	549	581	611	636	659	679	702	2.2	1.1	0.8	0.6
Inland waterway navigation	280	282	303	320	338	354	367	378	387	394	1.3	1.0	0.7	0.4
Final Energy Demand (ktoe)	**362402**	**372960**	**383672**	**373058**	**345506**	**330514**	**312458**	**296013**	**275503**	**256371**	**0.0**	**-1.2**	**-1.1**	**-1.4**
by transport mode														
Passenger transport	**254276**	**258846**	**265429**	**255503**	**234677**	**224878**	**211302**	**198701**	**183012**	**170235**	**-0.1**	**-1.3**	**-1.2**	**-1.5**
Public road transport	5028	5201	5184	5082	4660	4184	3830	3553	3332	3156	-0.2	-1.9	-1.6	-1.2
Private cars	169568	170749	169921	155856	133569	124904	115173	104531	92785	82961	-0.9	-2.2	-1.8	-2.3
2wheelers	7094	7192	7386	7622	7469	7141	6657	6227	5703	5162	0.6	-0.6	-1.4	-1.9
Passenger light duty vehicles	18828	19762	20166	18880	17549	16211	14747	14036	13148	12225	-0.5	-1.5	-1.4	-1.4
Rail	1960	1985	2130	2188	2287	2258	2247	2197	2126	2079	1.0	0.3	-0.3	-0.6
Aviation	49703	51804	58590	63727	66904	67877	66318	65761	63450	62164	2.1	0.6	-0.3	-0.6
Inland navigation	2094	2153	2053	2148	2239	2303	2330	2396	2468	2487	0.0	0.7	0.4	0.4
Freight transport	**108126**	**114114**	**118242**	**117555**	**110830**	**105636**	**101156**	**97312**	**92491**	**86137**	**0.3**	**-1.1**	**-0.8**	**-1.2**
Heavy duty vehicles	92279	98249	101690	101540	94571	89525	85019	81301	76721	70784	0.3	-1.3	-1.0	-1.4
Freight light duty vehicles	5079	5174	5059	4613	4514	4273	3924	3803	3618	3401	-1.1	-0.8	-1.2	-1.1
Rail	7476	7383	8010	7686	7776	7660	7885	7755	7621	7403	0.4	0.0	0.1	-0.5
Inland waterway navigation	3292	3308	3483	3717	3969	4179	4328	4454	4530	4549	1.2	1.2	0.6	0.2
by fuel														
Oil products	**352414**	**353487**	**355658**	**330675**	**293455**	**261608**	**229484**	**192401**	**147595**	**103494**	**-0.7**	**-2.3**	**-3.0**	**-6.0**
Gasoline	114297	106546	101741	88866	73017	63716	52803	41139	31347	23623	-1.8	-3.3	-4.3	-5.4
Diesel	182919	188835	185293	164981	139462	114466	95931	77552	58862	33787	-1.3	-3.6	-3.8	-8.0
Kerosene	49703	51804	58590	63727	66904	67481	64123	57913	44446	35250	2.1	0.6	-1.5	-4.8
Liquefied Petroleum Gas	4520	5385	9191	12304	13316	15243	16008	15287	12558	10534	8.6	2.2	0.0	-3.7
Residual fuel oil	974	916	843	797	756	702	619	510	382	300	-1.4	-1.3	-3.2	-5.2
Biofuels	**3129**	**11984**	**18220**	**29069**	**34348**	**47106**	**57375**	**76040**	**99109**	**122707**	**9.3**	**4.9**	**4.9**	**4.9**
Bio Gasoline	581	3338	5105	7816	8807	10712	13625	18510	22404	24674	8.9	3.2	5.6	2.9
Bio Diesel	2548	8646	13114	21247	25441	33774	38620	45958	52371	61728	9.4	4.7	3.1	3.0
Bio Kerosene	0	0	0	0	0	396	2195	7848	19004	26914			34.8	13.1
DME	0	0	1	4	52	1037	1509	2139	3965	7999	36.2	72.8	7.5	14.1
Bio Heavy	0	0	0	0	0	8	47	119	228	310			30.5	10.1
Biogas	0	0	0	1	48	1179	1378	1465	1137	1081	108.4	100.2	2.2	-3.0
Electricity	6353	6780	7678	9074	10917	12870	15191	17034	19022	21011	**3.0**	**3.6**	**2.8**	**2.1**
Natural Gas	506	710	2115	4240	6684	8553	9663	9139	7594	6140	**19.6**	**7.3**	**0.7**	**-3.9**
Hydrogen	0	0	0	0	102	377	745	1399	2182	3019		**97.6**	**14.0**	**8.0**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.5**	**34.4**	**30.6**	**27.6**	**25.0**	**22.8**	**20.6**	**18.9**	**-1.4**	**-2.2**	**-1.9**	**-1.9**
Public road transport	9.6	9.5	9.2	8.6	7.6	6.7	6.0	5.3	4.9	4.6	-1.0	-2.5	-2.3	-1.6
Private cars	39.4	38.2	35.2	31.4	26.7	23.7	21.2	18.9	16.5	14.7	-1.9	-2.8	-2.3	-2.5
2wheelers	47.3	46.4	44.5	42.9	40.1	36.7	33.0	30.0	26.9	24.1	-0.8	-1.6	-2.0	-2.2
Passenger light duty vehicles	82.8	82.7	78.0	69.9	63.3	55.4	48.7	45.4	42.1	38.9	-1.7	-2.3	-2.0	-1.5
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.1	63.4	57.4	53.8	50.8	48.0	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.5	49.7	49.2	48.5	47.7	-0.3	-0.2	-0.3	-0.3
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**41.0**	**38.2**	**34.3**	**31.2**	**28.9**	**26.9**	**25.1**	**23.2**	**-1.1**	**-2.0**	**-1.5**	**-1.5**
Heavy duty vehicles	53.0	52.3	50.4	47.4	42.1	38.2	35.2	32.6	30.3	28.0	-1.0	-2.1	-1.6	-1.5
Freight light duty vehicles	84.8	84.4	79.6	71.7	65.3	57.4	50.6	47.1	43.8	40.7	-1.6	-2.2	-2.0	-1.5
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.8	11.2	10.5	-1.8	-1.1	-0.6	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.5	-0.1	0.2	0.0	-0.2
CO_2 EMISSIONS (in ktons CO_2)	**1053078**	**1057753**	**1066192**	**995078**	**889032**	**796919**	**703424**	**591950**	**455595**	**320337**	**-0.6**	**-2.2**	**-2.9**	**-6.0**
Passenger transport	740076	737556	743272	690868	617111	557586	494530	415412	312688	232855	-0.7	-2.1	-2.9	-5.6
Public road transport	15225	15249	14816	14006	12447	10180	8319	6646	5018	3339	-0.8	-3.1	-4.2	-6.7
Private cars	493354	483807	470839	410673	335199	285859	242858	191493	138943	95811	-1.6	-3.6	-3.9	-6.7
2wheelers	20311	20134	20334	20335	19752	17704	15694	13144	10450	8153	0.1	-1.4	-2.9	-4.7
Passenger light duty vehicles	56340	57220	56479	49693	43966	36468	30729	26423	21813	17438	-1.4	-3.0	-3.2	-4.1
Rail	1085	967	814	649	532	394	261	134	45	4	-3.9	-4.9	-10.2	-30.3
Aviation	147321	153548	173660	188886	198302	200014	190062	171655	131738	104482	2.1	0.6	-1.5	-4.8
Inland navigation	6439	6631	6330	6625	6911	6967	6606	5917	4682	3629	0.0	0.5	-1.6	-4.8
Freight transport	313002	320197	322920	304211	271921	239333	208894	176538	142906	87482	**-0.5**	**-2.4**	**-3.0**	**-6.8**
Heavy duty vehicles	279315	288093	291047	275530	244458	214192	186281	157046	127712	75896	-0.4	-2.5	-3.1	-7.0
Freight light duty vehicles	15142	14919	14123	12144	11329	9723	8297	7289	6154	5025	-2.0	-2.2	-2.8	-3.7
Rail	8377	6977	7010	5085	3912	2847	2169	1413	770	334	-3.1	-5.6	-6.8	-13.4
Inland waterway navigation	10168	10209	10740	11452	12222	12572	12147	10790	8271	6226	1.2	0.9	-1.5	-5.3

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B) **EU27: Dominant biomass with energy efficiency standards**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260703**	**277089**	**285031**	**277468**	**294159**	**304116**	**310156**	**313897**	**316287**	**0.9**	**0.3**	**0.5**	**0.2**
Diesel Conventional	87565	101810	105046	88059	61052	47382	38420	29784	19494	11775	-1.4	-6.0	-4.5	-8.9
Diesel Hybrid	0	204	2266	12182	24713	30777	32438	35362	40694	43632	50.5	9.7	1.4	2.1
Diesel plug-in hybrid	0	0	625	6589	13059	18730	22227	26035	31347	36046		11.0	3.3	3.3
Gasoline Conventional	150450	149253	150583	132175	97155	78525	63127	46764	28912	16728	-1.2	-5.1	-5.1	-9.8
Gasoline Hybrid	24	221	2414	15734	33926	45591	50705	56823	65465	69131	53.2	11.2	2.2	2.0
Gasoline plug-in hybrid	0	0	579	7916	16608	26127	32468	38778	46785	53639		12.7	4.0	3.3
LPG	4849	8234	13080	17109	18434	21503	23309	22558	18170	14522	7.6	2.3	0.5	-4.3
CNG	718	976	2476	5057	8549	12515	14946	14942	12323	9773	17.9	9.5	1.8	-4.2
E85	0	6	17	99	669	2202	3976	5622	6961	7844	32.6	36.3	9.8	3.4
Electric	0	0	3	110	2916	9523	20207	29640	37656	44616		56.3	12.0	4.2
Hydrogen	0	0	0	1	386	1283	2292	3849	6091	8582		106.3	11.6	8.3
2wheelers	**31568**	**33227**	**36239**	**39410**	**41965**	**44240**	**46060**	**47446**	**48393**	**48898**	**1.7**	**1.2**	**0.7**	**0.3**
Gasoline	31568	33227	36239	39407	41846	41956	41527	40377	38316	35707	1.7	0.6	-0.4	-1.2
Electricity	0	0	0	3	119	2284	4533	7069	10077	13191		92.5	12.0	6.4
HDVs, buses and coaches	**8580**	**9479**	**10157**	**10638**	**11018**	**11643**	**12083**	**12476**	**12685**	**12752**	**1.2**	**0.9**	**0.7**	**0.2**
Diesel Conventional	8565	9457	9967	9921	8139	6963	5909	5342	5135	4814	0.5	-3.5	-2.6	-1.0
Diesel Hybrid	0	6	134	620	2708	4232	5438	6068	6114	6087	60.1	21.2	3.7	0.0
LPG	2	2	12	37	73	145	216	303	403	495	35.3	14.7	7.7	5.0
CNG	13	15	44	60	75	138	190	247	311	359	15.1	8.8	6.0	3.8
Electric	0	0	0	1	23	153	298	444	584	769		60.9	11.3	5.6
Hydrogen	0	0	0	0	0	12	32	73	136	228		89.2	19.4	12.1
Total annual cost excl. disutility (in million Euro'08)	**2421021**	**2603713**	**2804694**	**3057861**	**3288745**	**3480459**	**3656358**	**3813535**	**3966950**	**4105681**	**1.6**	**1.3**	**0.9**	**0.7**
Passenger transport	**1993286**	**2130926**	**2262608**	**2463686**	**2653990**	**2817628**	**2962854**	**3091128**	**3215258**	**3320921**	**1.5**	**1.4**	**0.9**	**0.7**
Public road transport	47158	52715	56136	60131	64996	66296	67950	69753	71685	73220	1.3	1.0	0.5	0.5
Private cars	1590463	1692338	1771659	1911059	2044597	2161623	2265915	2351716	2424832	2484135	1.2	1.2	0.8	0.5
2wheelers	46744	48915	52919	58694	65356	68388	72074	75167	78606	80419	1.8	1.5	0.9	0.7
Passenger light duty vehicles	113667	124439	135312	144078	150282	158771	168449	175926	183019	188663	1.5	1.0	1.0	0.7
Rail	74543	78186	81210	83913	87361	88451	89253	92155	96769	99786	0.7	0.5	0.4	0.8
Aviation	112942	126148	156465	196060	231039	263477	288235	315000	348191	381774	4.5	3.0	1.8	1.9
Inland navigation	7770	8185	8907	9750	10359	10622	10979	11410	12157	12925	1.8	0.9	0.7	1.3
Freight transport	**427736**	**472787**	**542086**	**594175**	**634755**	**662831**	**693504**	**722407**	**751692**	**784759**	**2.3**	**1.1**	**0.9**	**0.8**
Heavy duty vehicles	298800	338403	392456	432613	463749	484230	509553	533453	558058	585381	2.5	1.1	1.0	0.9
Freight light duty vehicles	31420	33154	34516	35591	39099	42167	45189	48205	50942	53080	0.7	1.7	1.3	1.0
Rail	55914	58699	67839	74971	77630	79667	79706	79766	79386	80381	2.5	0.6	0.0	0.1
Inland waterway navigation	41602	42531	47275	51000	54277	56767	59056	60983	63305	65918	1.8	1.1	0.7	0.8
External costs (in million Euro'08) (1)	**447714**	**404189**	**409268**	**417794**	**433495**	**449281**	**456717**	**465919**	**469588**	**469883**	**0.3**	**0.7**	**0.4**	**0.1**
Disutility costs (in million Euro'08)	**0**	**84**	**31741**	**49465**	**109499**	**89191**	**98137**	**111420**	**145808**	**176007**	**89.1**	**6.1**	**2.3**	**4.7**
Passenger transport	0	75	13938	34513	90376	69894	74622	85340	110361	125399	84.5	7.3	2.0	3.9
Freight transport	0	9	17803	14953	19123	19297	23515	26080	35446	50608	109.9	2.6	3.1	6.9
Total costs (incl. disutility and external costs)	**2421021**	**2603798**	**2836435**	**3107326**	**3398244**	**3569650**	**3754494**	**3924955**	**4112758**	**4281688**	**1.8**	**1.4**	**1.0**	**0.9**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: Dominant electricity-fuel cell success with CO2 standards **SUMMARY (A)**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6511**	**7072**	**7423**	**7681**	**8197**	**8588**	**8847**	**9072**	**9317**	**1.3**	**1.0**	**0.8**	**0.5**
Public road transport	526	545	563	598	629	640	654	674	688	694	0.9	0.7	0.5	0.3
Private cars	4309	4472	4821	4951	4990	5300	5531	5642	5771	5918	1.0	0.7	0.6	0.5
2wheelers	150	155	166	176	185	195	202	209	216	222	1.3	1.0	0.7	0.6
Passenger light duty vehicles	227	239	259	270	278	296	309	318	324	332	1.2	0.9	0.7	0.4
Rail	461	482	524	567	614	644	678	717	755	779	1.6	1.3	1.1	0.8
Aviation	527	577	700	819	942	1076	1167	1238	1269	1320	3.6	2.8	1.4	0.6
Inland navigation	40	41	40	42	44	45	46	48	50	52	0.3	0.8	0.6	0.7
Freight transport activity (Gtkm)	**2495**	**2664**	**2885**	**3070**	**3226**	**3372**	**3487**	**3598**	**3656**	**3703**	**1.4**	**0.9**	**0.6**	**0.3**
Heavy duty vehicles	1740	1880	2016	2135	2235	2330	2401	2472	2496	2515	1.3	0.9	0.6	0.2
Freight light duty vehicles	60	61	64	64	69	75	78	82	84	86	0.5	1.5	0.9	0.4
Rail	414	440	503	550	582	613	639	664	686	706	2.2	1.1	0.8	0.6
Inland waterway navigation	280	282	303	321	339	355	369	380	391	396	1.3	1.0	0.7	0.4
Final Energy Demand (ktoe)	**362402**	**372960**	**383858**	**370606**	**336534**	**316432**	**296211**	**267534**	**243999**	**227916**	**-0.1**	**-1.6**	**-1.7**	**-1.6**
by transport mode														
Passenger transport	**254276**	**258846**	**265312**	**252603**	**225595**	**211191**	**195603**	**170874**	**152961**	**143974**	**-0.2**	**-1.8**	**-2.1**	**-1.7**
Public road transport	5028	5201	5182	5124	4750	4202	3747	3389	3059	2825	-0.2	-2.0	-2.1	-1.8
Private cars	169568	170749	169831	153382	125386	113236	102771	81582	68260	61924	-1.1	-3.0	-3.2	-2.7
2wheelers	7094	7192	7386	7380	7030	6279	5165	3854	2731	2005	0.3	-1.6	-4.8	-6.3
Passenger light duty vehicles	18828	19762	20141	18676	16949	14733	12438	10925	9934	9413	-0.6	-2.3	-2.9	-1.5
Rail	1960	1985	2130	2191	2289	2252	2227	2174	2089	2023	1.0	0.3	-0.4	-0.7
Aviation	49703	51804	58589	63706	66959	68198	66942	66568	64436	63309	2.1	0.7	-0.2	-0.5
Inland navigation	2094	2153	2053	2145	2233	2291	2312	2383	2453	2474	0.0	0.7	0.4	0.4
Freight transport	**108126**	**114114**	**118546**	**118003**	**110939**	**105241**	**100608**	**96660**	**91038**	**83942**	**0.3**	**-1.1**	**-0.8**	**-1.4**
Heavy duty vehicles	92279	98249	101999	102029	94809	89529	85086	81472	76138	69430	0.4	-1.3	-0.9	-1.6
Freight light duty vehicles	5079	5174	5054	4564	4362	3841	3260	2911	2641	2492	-1.2	-1.7	-2.7	-1.5
Rail	7476	7383	8010	7691	7788	7676	7913	7792	7676	7437	0.4	0.0	0.1	-0.5
Inland waterway navigation	3292	3308	3483	3717	3980	4195	4349	4485	4582	4583	1.2	1.2	0.7	0.2
by fuel														
Oil products	**352414**	**353487**	**355818**	**327486**	**283028**	**250197**	**220238**	**175390**	**134567**	**107564**	**-0.8**	**-2.7**	**-3.5**	**-4.8**
Gasoline	114297	106546	101675	86405	65691	51632	39863	24867	15985	11965	-2.1	-5.0	-7.0	-7.1
Diesel	182919	188835	185508	164368	137134	116335	100916	79897	63022	46996	-1.4	-3.4	-3.7	-5.2
Kerosene	49703	51804	58589	63706	66959	67808	64781	58856	45790	39534	2.1	0.6	-1.4	-3.9
Liquefied Petroleum Gas	4520	5385	9203	12210	12489	13720	14057	11235	9320	8638	8.5	1.2	-2.0	-2.6
Residual fuel oil	974	916	843	797	756	701	621	535	450	433	-1.4	-1.3	-2.7	-2.1
Biofuels	**3129**	**11984**	**18232**	**29258**	**30765**	**32807**	**34576**	**40870**	**51710**	**57890**	**9.3**	**1.2**	**2.2**	**3.5**
Bio Gasoline	581	3338	5101	8011	7446	7990	8653	7592	6846	6043	9.2	0.0	-0.5	-2.3
Bio Diesel	2548	8646	13131	21247	23318	24377	23650	25333	25718	27005	9.4	1.4	0.4	0.6
Bio Kerosene	0	0	0	0	0	390	2161	7712	18646	23775			34.8	11.9
DME	0	0	0	0	1	3	3	3	4	6	3.9	26.2	1.2	7.8
Bio Heavy	0	0	0	0	0	8	43	91	157	168			27.7	6.4
Biogas	0	0	0	0	0	39	66	139	340	892	41.1	110.6	13.4	20.4
Electricity	6353	6780	7702	9474	11691	15160	18651	22411	25582	28191	**3.4**	**4.8**	**4.0**	**2.3**
Natural Gas	506	710	2106	4145	6119	9132	9919	7490	5475	3972	**19.3**	**8.2**	**-2.0**	**-6.1**
Hydrogen	0	0	0	243	4930	9136	12827	21373	26665	30299		**43.7**	**8.9**	**3.6**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.5**	**34.0**	**29.4**	**25.8**	**22.8**	**19.3**	**16.9**	**15.5**	**-1.5**	**-2.7**	**-2.8**	**-2.2**
Public road transport	9.6	9.5	9.2	8.6	7.6	6.6	5.7	5.0	4.4	4.1	-1.1	-2.6	-2.6	-2.1
Private cars	39.4	38.2	35.2	31.0	25.1	21.4	18.6	14.5	11.8	10.5	-2.1	-3.6	-3.8	-3.2
2wheelers	47.3	46.4	44.5	41.8	37.9	32.2	25.5	18.5	12.7	9.0	-1.0	-2.6	-5.4	-6.9
Passenger light duty vehicles	82.8	82.7	77.9	69.2	60.9	49.7	40.2	34.3	30.7	28.4	-1.8	-3.3	-3.6	-1.9
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.1	63.4	57.4	53.8	50.8	48.0	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.5	49.7	49.3	48.7	47.9	-0.3	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**41.1**	**38.4**	**34.4**	**31.2**	**28.9**	**26.9**	**24.9**	**22.7**	**-1.1**	**-2.1**	**-1.5**	**-1.7**
Heavy duty vehicles	53.0	52.3	50.6	47.8	42.4	38.4	35.4	33.0	30.5	27.6	-0.9	-2.2	-1.5	-1.8
Freight light duty vehicles	84.8	84.4	79.5	71.0	63.0	51.4	41.5	35.5	31.6	29.1	-1.7	-3.2	-3.6	-2.0
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.7	11.2	10.5	-1.8	-1.1	-0.6	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	-0.1	0.2	0.0	-0.2
CO_2 EMISSIONS (in ktons CO_2)	**1053078**	**1057753**	**1066668**	**985593**	**857445**	**765892**	**678315**	**539829**	**413806**	**329177**	**-0.7**	**-2.5**	**-3.4**	**-4.8**
Passenger transport	740076	737556	742885	679533	582634	519728	454412	343793	248926	204830	-0.8	-2.6	-4.0	-5.0
Public road transport	15225	15249	14809	14114	12688	10507	8469	6947	5418	4464	-0.8	-2.9	-4.1	-4.3
Private cars	493354	483807	470542	400857	303204	251736	209412	128588	81663	61151	-1.9	-4.5	-6.5	-7.2
2wheelers	20311	20134	20334	19632	18462	15378	11945	7776	4663	2989	-0.3	-2.4	-6.6	-9.1
Passenger light duty vehicles	56340	57220	56397	48839	42390	33727	25609	19567	15766	13534	-1.6	-3.6	-5.3	-3.6
Rail	1085	967	814	649	532	400	269	146	51	5	-3.9	-4.7	-9.6	-28.5
Aviation	147321	153548	173658	188825	198466	200983	192012	174449	135723	117178	2.1	0.6	-1.4	-3.9
Inland navigation	6439	6631	6330	6617	6891	6997	6694	6320	5643	5509	0.0	0.6	-1.0	-1.4
Freight transport	313002	320197	323782	306060	274811	246164	223903	196036	164880	124347	**-0.5**	**-2.2**	**-2.3**	**-4.5**
Heavy duty vehicles	279315	288093	291927	277574	247711	221709	202418	177490	149355	110177	-0.4	-2.2	-2.2	-4.7
Freight light duty vehicles	15142	14919	14105	11947	10932	8811	6737	5260	4222	3600	-2.2	-3.0	-5.0	-3.7
Rail	8377	6977	7010	5086	3914	2878	2236	1532	865	428	-3.1	-5.5	-6.1	-12.0
Inland waterway navigation	10168	10209	10740	11454	12255	12765	12512	11755	10438	10142	1.2	1.1	-0.8	-1.5

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B) | **EU27: Dominant electricity-fuel cell success with CO2 standards**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260703**	**277081**	**284430**	**276914**	**296270**	**310956**	**318564**	**324854**	**334283**	**0.9**	**0.4**	**0.7**	**0.5**
Diesel Conventional	87565	101810	104922	85928	55642	40315	30761	18515	10453	7265	-1.7	-7.3	-7.5	-8.9
Diesel Hybrid	0	204	2258	12156	21715	24608	23246	16512	11538	9488	50.5	7.3	-3.9	-5.4
Diesel plug-in hybrid	0	0	749	8672	15322	19645	21843	23168	23378	23295		8.5	1.7	0.1
Gasoline Conventional	150450	149253	150442	128290	86279	62872	46921	27127	14046	8736	-1.5	-6.9	-8.1	-10.7
Gasoline Hybrid	24	221	2407	15807	28744	33363	32376	24406	18258	15352	53.3	7.8	-3.1	-4.5
Gasoline plug-in hybrid	0	0	711	10430	19199	25972	29883	32961	34629	35028		9.6	2.4	0.6
LPG	4849	8234	13095	16976	17183	18916	19450	14927	11119	10025	7.5	1.1	-2.3	-3.9
CNG	718	976	2476	4952	7510	10145	11209	8342	5556	4255	17.6	7.4	-1.9	-6.5
E85	0	6	17	91	379	640	905	851	807	810	31.5	21.5	2.9	-0.5
Electric	0	0	4	186	5845	21402	39359	63507	81551	92128		60.7	11.5	3.8
Hydrogen	0	0	2	941	19095	38391	55002	88247	113519	127900		44.9	8.7	3.8
2wheelers	**31568**	**33227**	**36238**	**39104**	**41652**	**44020**	**45929**	**47298**	**48762**	**50165**	**1.6**	**1.2**	**0.7**	**0.6**
Gasoline	31568	33227	36238	37984	39049	35791	30369	22227	15016	10283	1.3	-0.6	-4.7	-7.4
Electricity	0	0	0	1120	2603	8228	15560	25072	33746	39882		22.1	11.8	4.8
HDVs, buses and coaches	**8580**	**9479**	**10156**	**10636**	**11007**	**11627**	**12054**	**12433**	**12580**	**12688**	**1.2**	**0.9**	**0.7**	**0.2**
Diesel Conventional	8565	9457	10030	10084	8309	6953	5654	4833	4336	3739	0.6	-3.6	-3.6	-2.5
Diesel Hybrid	0	6	69	429	2467	3900	4987	5443	5139	4668	54.3	24.7	3.4	-1.5
LPG	2	2	12	41	86	162	233	314	385	424	36.8	14.7	6.9	3.1
CNG	13	15	44	81	127	240	336	417	470	490	18.7	11.5	5.7	1.6
Electric	0	0	0	1	17	290	624	991	1526	2179		87.3	13.1	8.2
Hydrogen	0	0	0	0	1	83	220	436	724	1188		113.0	18.0	10.6
Total annual cost excl. disutility (in million Euro'08)	**2421033**	**2603713**	**2804819**	**3059979**	**3288211**	**3464586**	**3629088**	**3778917**	**3922714**	**4032346**	**1.6**	**1.2**	**0.9**	**0.7**
Passenger transport	**1993298**	**2130926**	**2262613**	**2464939**	**2651359**	**2799526**	**2932982**	**3053443**	**3165871**	**3247645**	**1.5**	**1.3**	**0.9**	**0.6**
Public road transport	47158	52715	56136	60109	64812	65622	66682	68302	69814	70584	1.3	0.9	0.4	0.3
Private cars	1590475	1692338	1771677	1911598	2040861	2140873	2232989	2310086	2367702	2401056	1.2	1.1	0.8	0.4
2wheelers	46744	48915	52918	59155	65788	68693	72680	76044	79365	80838	1.9	1.5	1.0	0.6
Passenger light duty vehicles	113667	124439	135301	144279	150856	160776	170156	177559	187936	194117	1.5	1.1	1.0	0.9
Rail	74543	78186	81210	84063	87421	88096	88386	91060	95067	97077	0.7	0.5	0.3	0.6
Aviation	112942	126148	156464	195998	231295	264914	291228	319091	353989	391306	4.5	3.1	1.9	2.1
Inland navigation	7770	8185	8908	9738	10327	10551	10861	11301	11998	12667	1.8	0.8	0.7	1.1
Freight transport	**427736**	**472787**	**542205**	**595039**	**636851**	**665060**	**696106**	**725474**	**756844**	**784701**	**2.3**	**1.1**	**0.9**	**0.8**
Heavy duty vehicles	298800	338403	392572	433269	465445	485887	511653	535876	561838	585074	2.5	1.2	1.0	0.9
Freight light duty vehicles	31420	33154	34518	35665	39169	42293	45060	47998	50972	52722	0.7	1.7	1.3	0.9
Rail	55914	58699	67840	75055	77796	79910	80053	80229	80132	80864	2.5	0.6	0.0	0.1
Inland waterway navigation	41602	42531	47276	51050	54442	56971	59340	61371	63902	66041	1.8	1.1	0.7	0.7
External costs (in million Euro'08) (1)	**447714**	**404189**	**409352**	**417034**	**428601**	**442600**	**449053**	**448611**	**451005**	**455110**	**0.3**	**0.6**	**0.1**	**0.1**
Disutility costs (in million Euro'08)	**0**	**84**	**31943**	**53548**	**110239**	**78302**	**72177**	**86099**	**102108**	**96986**	**90.6**	**3.9**	**1.0**	**1.2**
Passenger transport	0	75	14032	37454	89408	57303	46668	57526	62949	50285	86.0	4.3	0.0	-1.3
Freight transport	0	9	17911	16094	20831	20999	25509	28573	39159	46701	111.5	2.7	3.1	5.0
Total costs (incl. disutility and external costs)	**2421033**	**2603798**	**2836762**	**3113526**	**3398449**	**3542888**	**3701265**	**3865016**	**4024823**	**4129332**	**1.8**	**1.3**	**0.9**	**0.7**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: Dominant electricity-fuel cell success with energy efficiency standards **SUMMARY (A)**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6511**	**7072**	**7421**	**7669**	**8187**	**8582**	**8837**	**9066**	**9320**	**1.3**	**1.0**	**0.8**	**0.5**
Public road transport	526	545	563	580	609	624	643	670	686	694	0.6	0.7	0.7	0.3
Private cars	4309	4472	4821	4965	4995	5302	5532	5634	5762	5917	1.1	0.7	0.6	0.5
2wheelers	150	155	166	178	186	195	204	209	215	220	1.4	1.0	0.7	0.5
Passenger light duty vehicles	227	239	259	270	279	297	311	320	328	338	1.2	1.0	0.7	0.5
Rail	461	482	524	566	613	645	679	718	756	780	1.6	1.3	1.1	0.8
Aviation	527	577	700	820	942	1077	1167	1237	1269	1320	3.6	2.8	1.4	0.7
Inland navigation	40	41	40	42	44	46	47	48	50	52	0.3	0.8	0.6	0.7
Freight transport activity (Gtkm)	**2495**	**2664**	**2886**	**3071**	**3226**	**3374**	**3489**	**3599**	**3659**	**3710**	**1.4**	**0.9**	**0.6**	**0.3**
Heavy duty vehicles	1740	1880	2016	2136	2235	2331	2402	2472	2497	2521	1.3	0.9	0.6	0.2
Freight light duty vehicles	60	61	64	64	70	75	79	83	86	89	0.5	1.6	1.0	0.7
Rail	414	440	503	550	582	612	639	664	686	705	2.2	1.1	0.8	0.6
Inland waterway navigation	280	282	303	321	339	355	369	380	391	395	1.3	1.0	0.7	0.4
Final Energy Demand (ktoe)	**362402**	**372960**	**383549**	**371167**	**336773**	**316461**	**295741**	**262823**	**234255**	**213145**	**0.0**	**-1.6**	**-1.8**	**-2.1**
by transport mode														
Passenger transport	**254276**	**258846**	**265312**	**253784**	**226272**	**211659**	**195886**	**168020**	**145583**	**131377**	**-0.2**	**-1.8**	**-2.3**	**-2.4**
Public road transport	5028	5201	5182	4847	4396	3913	3488	3158	2828	2617	-0.7	-2.1	-2.1	-1.9
Private cars	169568	170749	169831	154509	125906	113427	102550	78593	62044	52038	-1.0	-3.0	-3.6	-4.0
2wheelers	7094	7192	7386	7622	7435	6719	6035	4854	3482	2211	0.6	-1.3	-3.2	-7.6
Passenger light duty vehicles	18828	19762	20141	18708	16996	14799	12296	10326	8278	6714	-0.5	-2.3	-3.5	-4.2
Rail	1960	1985	2130	2187	2286	2252	2229	2179	2093	2027	1.0	0.3	-0.3	-0.7
Aviation	49703	51804	58589	63755	67008	68247	66970	66523	64400	63294	2.1	0.7	-0.3	-0.5
Inland navigation	2094	2153	2053	2156	2245	2302	2319	2387	2457	2476	0.0	0.7	0.4	0.4
Freight transport	**108126**	**114114**	**118237**	**117383**	**110502**	**104802**	**99854**	**94803**	**88673**	**81768**	**0.3**	**-1.1**	**-1.0**	**-1.5**
Heavy duty vehicles	92279	98249	101691	101401	94347	89052	84340	79739	74183	67953	0.3	-1.3	-1.1	-1.6
Freight light duty vehicles	5079	5174	5054	4574	4388	3882	3257	2784	2237	1811	-1.2	-1.6	-3.3	-4.2
Rail	7476	7383	8010	7690	7788	7674	7910	7794	7676	7431	0.4	0.0	0.2	-0.5
Inland waterway navigation	3292	3308	3483	3717	3979	4193	4348	4486	4577	4573	1.2	1.2	0.7	0.2
by fuel														
Oil products	**352414**	**353487**	**355531**	**328770**	**281946**	**248735**	**218425**	**174470**	**131812**	**104178**	**-0.7**	**-2.8**	**-3.5**	**-5.0**
Gasoline	114297	106546	101675	87565	66189	51893	40397	27309	17840	12350	-1.9	-5.1	-6.2	-7.6
Diesel	182919	188835	185222	164409	135601	114730	99362	79515	63088	48490	-1.4	-3.5	-3.6	-4.8
Kerosene	49703	51804	58589	63755	67008	67856	64808	58816	45764	40000	2.1	0.6	-1.4	-3.8
Liquefied Petroleum Gas	4520	5385	9203	12243	12391	13554	13237	8294	4672	2906	8.6	1.0	-4.8	-10.0
Residual fuel oil	974	916	843	798	757	702	622	536	450	432	-1.4	-1.3	-2.7	-2.1
Biofuels	**3129**	**11984**	**18211**	**28666**	**32207**	**34439**	**36322**	**43064**	**53560**	**56326**	**9.1**	**1.9**	**2.3**	**2.7**
Bio Gasoline	581	3338	5101	7934	7819	8436	9194	8169	7347	5729	9.0	0.6	-0.3	-3.5
Bio Diesel	2548	8646	13109	20732	24386	25564	24861	26993	27198	26554	9.1	2.1	0.5	-0.2
Bio Kerosene	0	0	0	0	0	390	2162	7707	18636	23295			34.8	11.7
DME	0	0	0	0	1	3	3	3	4	6	3.8	26.2	1.3	7.7
Bio Heavy	0	0	0	0	0	8	43	91	157	168			27.6	6.3
Biogas	0	0	0	0	0	39	60	101	218	573	41.0	110.3	10.1	19.0
Electricity	6353	6780	7702	9378	11640	15159	19047	26553	32838	38066	**3.3**	**4.9**	**5.8**	**3.7**
Natural Gas	506	710	2105	4121	6041	8956	9208	5555	3191	1937	**19.2**	**8.1**	**-4.7**	**-10.0**
Hydrogen	0	0	0	232	4940	9171	12738	13182	12853	12638		**44.4**	**3.7**	**-0.4**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.5**	**34.2**	**29.5**	**25.9**	**22.8**	**19.0**	**16.1**	**14.1**	**-1.5**	**-2.8**	**-3.0**	**-2.9**
Public road transport	9.6	9.5	9.2	8.4	7.2	6.3	5.4	4.7	4.1	3.8	-1.3	-2.8	-2.8	-2.2
Private cars	39.4	38.2	35.2	31.1	25.2	21.4	18.5	13.9	10.8	8.8	-2.0	-3.7	-4.2	-4.5
2wheelers	47.3	46.4	44.5	42.9	39.9	34.4	29.6	23.2	16.2	10.0	-0.8	-2.2	-3.9	-8.0
Passenger light duty vehicles	82.8	82.7	77.9	69.2	61.0	49.8	39.6	32.2	25.2	19.9	-1.8	-3.2	-4.2	-4.7
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.1	63.4	57.4	53.8	50.8	47.9	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.5	49.7	49.3	48.7	47.9	-0.3	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**41.0**	**38.2**	**34.2**	**31.1**	**28.6**	**26.3**	**24.2**	**22.0**	**-1.1**	**-2.1**	**-1.6**	**-1.8**
Heavy duty vehicles	53.0	52.3	50.4	47.5	42.2	38.2	35.1	32.3	29.7	27.0	-1.0	-2.1	-1.7	-1.8
Freight light duty vehicles	84.8	84.4	79.5	71.0	63.0	51.5	41.1	33.6	26.0	20.3	-1.7	-3.2	-4.2	-4.9
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.7	11.2	10.5	-1.8	-1.1	-0.7	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	-0.1	0.2	0.0	-0.2
CO$_2$ EMISSIONS (in ktons CO$_2$)	**1053078**	**1057753**	**1065787**	**989230**	**853883**	**761013**	**671356**	**533294**	**401671**	**316375**	**-0.7**	**-2.6**	**-3.5**	**-5.1**
Passenger transport	740076	737556	742885	684227	582879	518873	453357	347371	247841	196111	-0.7	-2.7	-3.9	-5.6
Public road transport	15225	15249	14809	13336	11676	9581	7612	6078	4577	3744	-1.3	-3.3	-4.4	-4.7
Private cars	493354	483807	470543	405203	303103	250432	207232	132029	83347	56610	-1.8	-4.7	-6.2	-8.1
2wheelers	20311	20134	20334	20335	19652	16521	14288	10252	6385	3441	0.1	-2.1	-4.7	-10.3
Passenger light duty vehicles	56340	57220	56396	49084	42376	33783	25149	18204	12186	8238	-1.5	-3.7	-6.0	-7.6
Rail	1085	967	814	649	532	400	269	146	51	5	-3.9	-4.7	-9.6	-28.5
Aviation	147321	153548	173658	188969	198612	201126	192090	174330	135644	118559	2.1	0.6	-1.4	-3.8
Inland navigation	6439	6631	6330	6651	6929	7030	6716	6331	5651	5514	0.0	0.6	-1.0	-1.4
Freight transport	313002	320197	322902	305003	271004	242140	217999	185923	153830	120264	**-0.5**	**-2.3**	**-2.6**	**-4.3**
Heavy duty vehicles	279315	288093	291047	276460	243878	217621	196565	167696	139264	107513	-0.4	-2.4	-2.6	-4.3
Freight light duty vehicles	15142	14919	14104	12004	10961	8883	6692	4938	3277	2204	-2.2	-3.0	-5.7	-7.7
Rail	8377	6977	7010	5085	3914	2878	2235	1531	865	428	-3.1	-5.5	-6.1	-12.0
Inland waterway navigation	10168	10209	10740	11454	12251	12759	12507	11757	10424	10119	1.2	1.1	-0.8	-1.5

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B)											EU27: Dominant electricity-fuel cell success with energy efficiency standards			
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260703**	**277081**	**284981**	**277365**	**296468**	**311035**	**318600**	**325031**	**335242**	**0.9**	**0.4**	**0.7**	**0.5**
Diesel Conventional	87565	101810	104922	86907	56368	40598	30399	14975	4487	433	-1.6	-7.3	-9.5	-29.8
Diesel Hybrid	0	204	2258	11750	21463	24597	24746	22311	18455	13694	50.0	7.7	-1.0	-4.8
Diesel plug-in hybrid	0	0	749	7972	14776	19323	21793	34058	44231	50181		9.3	5.8	4.0
Gasoline Conventional	150450	149253	150442	130204	87734	63502	45808	22123	6307	455	-1.4	-6.9	-10.0	-32.2
Gasoline Hybrid	24	221	2407	15113	28242	33173	34124	31078	25560	18167	52.6	8.2	-0.7	-5.2
Gasoline plug-in hybrid	0	0	711	9835	18741	25709	29761	43171	53436	58776		10.1	5.3	3.1
LPG	4849	8234	13095	17077	17177	18795	18437	11017	4306	1058	7.6	1.0	-5.2	-20.9
CNG	718	976	2476	4973	7512	10123	10700	6286	2238	356	17.7	7.4	-4.7	-25.0
E85	0	6	17	85	372	633	908	635	346	134	30.5	22.3	0.0	-14.4
Electric	0	0	4	180	5871	21519	39714	77364	115319	150024		61.3	13.7	6.8
Hydrogen	0	0	2	885	19108	38495	54645	55581	50344	41966		45.8	3.7	-2.8
2wheelers	**31568**	**33227**	**36238**	**39412**	**41964**	**44285**	**46413**	**47529**	**48611**	**49678**	**1.7**	**1.2**	**0.7**	**0.4**
Gasoline	31568	33227	36238	39405	41629	39131	37261	30125	20916	11052	1.7	-0.1	-2.6	-9.5
Electricity	0	0	0	6	334	5154	9152	17404	27694	38626		95.0	12.9	8.3
HDVs, buses and coaches	**8580**	**9479**	**10157**	**10613**	**10979**	**11606**	**12038**	**12424**	**12592**	**12720**	**1.1**	**0.9**	**0.7**	**0.2**
Diesel Conventional	8565	9457	9966	9699	7801	6497	5255	4298	3811	3279	0.3	-3.9	-4.0	-2.7
Diesel Hybrid	0	6	135	826	3004	4389	5373	5870	5522	4990	64.8	18.2	3.0	-1.6
LPG	2	2	12	32	68	141	207	272	336	373	33.5	15.9	6.8	3.2
CNG	13	15	44	44	57	168	255	323	376	398	11.7	14.3	6.7	2.1
Electric	0	0	0	12	49	327	722	1198	1780	2441		39.7	13.9	7.4
Hydrogen	0	0	0	0	1	85	227	463	767	1240		83.7	18.5	10.4
Total annual cost excl. disutility (in million Euro'08)	**2421033**	**2603713**	**2804698**	**3058922**	**3286449**	**3461702**	**3628225**	**3778018**	**3938947**	**4067545**	**1.6**	**1.2**	**0.9**	**0.7**
Passenger transport	**1993298**	**2130926**	**2262613**	**2464263**	**2650003**	**2797167**	**2932790**	**3053554**	**3183565**	**3284623**	**1.5**	**1.3**	**0.9**	**0.7**
Public road transport	47158	52715	56136	60164	64770	65390	66472	68275	69668	70400	1.3	0.8	0.4	0.3
Private cars	1590475	1692338	1771676	1911758	2041673	2142211	2237297	2314609	2392803	2446217	1.2	1.1	0.8	0.6
2wheelers	46744	48915	52918	58693	65110	67853	71347	74626	78565	80956	1.8	1.5	1.0	0.8
Passenger light duty vehicles	113667	124439	135301	143825	149275	157926	166947	174624	181442	185630	1.5	0.9	1.0	0.6
Rail	74543	78186	81210	83912	87369	88141	88530	91198	95229	97123	0.7	0.5	0.3	0.6
Aviation	112942	126148	156464	196119	231420	265039	291296	318898	353841	391615	4.5	3.1	1.9	2.1
Inland navigation	7770	8185	8908	9791	10386	10606	10901	11324	12016	12683	1.8	0.8	0.7	1.1
Freight transport	**427736**	**472787**	**542085**	**594659**	**636446**	**664535**	**695436**	**724463**	**755383**	**782922**	**2.3**	**1.1**	**0.9**	**0.8**
Heavy duty vehicles	298800	338403	392456	433033	465357	485925	511557	535339	561476	584925	2.5	1.2	1.0	0.9
Freight light duty vehicles	31420	33154	34516	35549	38879	41799	44540	47491	49967	51392	0.7	1.6	1.3	0.8
Rail	55914	58699	67839	75038	77784	79871	80027	80250	80109	80718	2.5	0.6	0.0	0.1
Inland waterway navigation	41602	42531	47275	51039	54425	56941	59311	61383	63831	65887	1.8	1.1	0.8	0.7
External costs (in million Euro'08) (1)	**447714**	**404189**	**409225**	**416336**	**427730**	**442093**	**449148**	**449708**	**452548**	**455087**	**0.3**	**0.6**	**0.2**	**0.1**
Disutility costs (in million Euro'08)	**0**	**84**	**31832**	**53933**	**113784**	**80867**	**73519**	**88441**	**103666**	**94083**	**90.8**	**4.1**	**0.9**	**0.6**
Passenger transport	0	75	14033	38359	93319	60546	48733	60656	66020	50607	86.5	4.7	0.0	-1.8
Freight transport	0	9	17799	15574	20465	20321	24785	27785	37645	43476	110.8	2.7	3.2	4.6
Total costs (incl. disutility and external costs)	**2421033**	**2603798**	**2836530**	**3112855**	**3400233**	**3542569**	**3701744**	**3866459**	**4042613**	**4161628**	**1.8**	**1.3**	**0.9**	**0.7**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: Dominant electricity-battery success with CO2 standards														SUMMARY (A)
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6511**	**7072**	**7424**	**7693**	**8195**	**8514**	**8660**	**8919**	**9191**	**1.3**	**1.0**	**0.6**	**0.6**
Public road transport	526	545	563	598	629	642	661	689	700	705	0.9	0.7	0.7	0.2
Private cars	4309	4472	4821	4952	5002	5297	5453	5453	5613	5789	1.0	0.7	0.3	0.6
2wheelers	150	155	166	176	185	195	202	207	214	220	1.3	1.0	0.6	0.6
Passenger light duty vehicles	227	239	259	270	278	296	307	310	317	326	1.2	0.9	0.5	0.5
Rail	461	482	524	567	614	646	683	730	767	790	1.6	1.3	1.2	0.8
Aviation	527	577	700	819	941	1074	1161	1223	1256	1309	3.6	2.7	1.3	0.7
Inland navigation	40	41	40	42	44	45	47	49	51	52	0.3	0.8	0.7	0.7
Freight transport activity (Gtkm)	**2495**	**2664**	**2885**	**3070**	**3226**	**3374**	**3488**	**3597**	**3657**	**3701**	**1.4**	**0.9**	**0.6**	**0.3**
Heavy duty vehicles	1740	1880	2016	2135	2235	2331	2401	2470	2496	2512	1.3	0.9	0.6	0.2
Freight light duty vehicles	60	61	64	64	70	76	80	84	86	88	0.5	1.7	1.0	0.5
Rail	414	440	503	550	582	612	638	663	684	705	2.2	1.1	0.8	0.6
Inland waterway navigation	280	282	303	321	339	355	368	380	390	396	1.3	1.0	0.7	0.4
Final Energy Demand (ktoe)	**362402**	**372960**	**383860**	**370922**	**342067**	**324907**	**298105**	**261298**	**235475**	**220088**	**-0.1**	**-1.3**	**-2.2**	**-1.7**
by transport mode														
Passenger transport	**254276**	**258846**	**265313**	**252900**	**231093**	**219209**	**196760**	**163592**	**143051**	**134282**	**-0.2**	**-1.4**	**-2.9**	**-2.0**
Public road transport	5028	5201	5182	5124	4754	4218	3787	3470	3140	2898	-0.1	-1.9	-1.9	-1.8
Private cars	169568	170749	169832	153660	130933	121264	104376	75380	59435	53306	-1.0	-2.3	-4.6	-3.4
2wheelers	7094	7192	7386	7380	7036	6285	5167	3850	2719	1994	0.3	-1.6	-4.8	-6.4
Passenger light duty vehicles	18828	19762	20141	18691	16947	14844	12273	10468	9399	8811	-0.6	-2.3	-3.4	-1.7
Rail	1960	1985	2130	2191	2291	2257	2244	2210	2124	2053	1.0	0.3	-0.2	-0.7
Aviation	49703	51804	58589	63710	66901	68051	66594	65808	63755	62723	2.1	0.7	-0.3	-0.5
Inland navigation	2094	2153	2053	2145	2231	2290	2318	2406	2479	2496	0.0	0.7	0.5	0.4
Freight transport	**108126**	**114114**	**118546**	**118022**	**110975**	**105698**	**101346**	**97706**	**92425**	**85806**	**0.3**	**-1.1**	**-0.8**	**-1.3**
Heavy duty vehicles	92279	98249	101999	102037	94815	89899	85768	82491	77528	71330	0.4	-1.3	-0.9	-1.4
Freight light duty vehicles	5079	5174	5054	4578	4394	3940	3330	2953	2663	2474	-1.2	-1.5	-2.8	-1.8
Rail	7476	7383	8010	7690	7787	7670	7904	7783	7662	7425	0.4	0.0	0.1	-0.5
Inland waterway navigation	3292	3308	3483	3717	3978	4189	4343	4479	4572	4577	1.2	1.2	0.7	0.2
by fuel														
Oil products	**352414**	**353487**	**355820**	**328217**	**290437**	**261363**	**226014**	**179393**	**135108**	**108437**	**-0.7**	**-2.3**	**-3.7**	**-4.9**
Gasoline	114297	106545	101672	86670	70361	58521	44602	26623	16704	12516	-2.0	-3.9	-7.6	-7.3
Diesel	182919	188834	185504	164806	139343	119489	102127	83415	64275	48510	-1.4	-3.2	-3.5	-5.3
Kerosene	49703	51804	58589	63710	66901	67662	64444	58182	45303	39165	2.1	0.6	-1.5	-3.9
Liquefied Petroleum Gas	4520	5387	9213	12236	13077	14989	14220	10634	8375	7811	8.5	2.1	-3.4	-3.0
Residual fuel oil	974	916	843	797	755	701	622	538	453	435	-1.4	-1.3	-2.6	-2.1
Biofuels	**3129**	**11984**	**18232**	**29040**	**32871**	**36739**	**38683**	**41108**	**53904**	**60705**	**9.3**	**2.4**	**1.1**	**4.0**
Bio Gasoline	581	3338	5101	8038	8395	9185	9336	8104	7107	6262	9.2	1.3	-1.2	-2.5
Bio Diesel	2548	8646	13131	21002	24475	27111	27091	25173	27928	30002	9.3	2.6	-0.7	1.8
Bio Kerosene	0	0	0	0	0	389	2150	7626	18452	23559			34.6	11.9
DME	0	0	0	0	1	3	3	3	4	6	3.9	26.7	0.5	7.1
Bio Heavy	0	0	0	0	0	8	43	91	158	169			27.7	6.4
Biogas	0	0	0	0	0	42	61	111	255	707	41.1	111.9	10.2	20.3
Electricity	6353	6780	7702	9497	12051	16053	21635	28273	33033	36199	**3.4**	**5.4**	**5.8**	**2.5**
Natural Gas	506	710	2106	4165	6517	10063	10114	7304	5268	3955	**19.4**	**9.2**	**-3.2**	**-5.9**
Hydrogen	0	0	0	3	191	689	1658	5219	8161	10791		**70.4**	**22.5**	**7.5**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.5**	**34.1**	**30.0**	**26.7**	**23.1**	**18.9**	**16.0**	**14.6**	**-1.5**	**-2.4**	**-3.4**	**-2.5**
Public road transport	9.6	9.5	9.2	8.6	7.6	6.6	5.7	5.0	4.5	4.1	-1.1	-2.6	-2.6	-2.0
Private cars	39.4	38.2	35.2	31.0	26.2	22.9	19.1	13.8	10.6	9.2	-2.1	-3.0	-4.9	-4.0
2wheelers	47.3	46.4	44.5	41.8	37.9	32.2	25.6	18.6	12.7	9.1	-1.0	-2.6	-5.4	-6.9
Passenger light duty vehicles	82.8	82.7	77.9	69.2	61.0	50.1	40.0	33.8	29.6	27.1	-1.8	-3.2	-3.9	-2.2
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.1	63.4	57.4	53.8	50.8	47.9	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.5	49.7	49.2	48.6	47.8	-0.3	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**41.1**	**38.4**	**34.4**	**31.3**	**29.1**	**27.2**	**25.3**	**23.2**	**-1.1**	**-2.0**	**-1.4**	**-1.6**
Heavy duty vehicles	53.0	52.3	50.6	47.8	42.4	38.6	35.7	33.4	31.1	28.4	-0.9	-2.1	-1.4	-1.6
Freight light duty vehicles	84.8	84.4	79.5	71.0	63.1	51.9	41.6	35.3	30.9	28.1	-1.7	-3.1	-3.8	-2.3
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.7	11.2	10.5	-1.8	-1.1	-0.6	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	-0.1	0.2	0.0	-0.2
CO$_2$ EMISSIONS (in ktons CO$_2$)	**1053078**	**1057753**	**1066670**	**987822**	**879945**	**800442**	**695549**	**551682**	**415313**	**332106**	**-0.7**	**-2.1**	**-3.7**	**-4.9**
Passenger transport	740076	737556	742888	682502	607512	557465	473698	348349	247317	203296	-0.8	-2.0	-4.6	-5.2
Public road transport	15225	15249	14809	14114	12701	10498	8641	7255	5768	4839	-0.8	-2.9	-3.6	-4.0
Private cars	493354	483807	470546	403540	328249	289029	229087	134054	80597	59850	-1.8	-3.3	-7.4	-7.7
2wheelers	20311	20134	20334	19632	18400	15099	11623	7778	4651	2976	-0.3	-2.6	-6.4	-9.2
Passenger light duty vehicles	56340	57220	56396	49115	42450	34894	26352	20283	16272	13984	-1.5	-3.4	-5.3	-3.7
Rail	1085	967	814	649	532	400	269	146	51	5	-3.9	-4.7	-9.6	-28.5
Aviation	147321	153548	173658	188836	198295	200550	191013	172451	134277	116084	2.1	0.6	-1.5	-3.9
Inland navigation	6439	6631	6330	6616	6885	6994	6713	6383	5702	5558	0.0	0.6	-0.9	-1.4
Freight transport	313002	320197	323782	305320	272433	242977	221851	203332	167996	128810	**-0.5**	**-2.3**	**-1.8**	**-4.5**
Heavy duty vehicles	279315	288093	291927	276754	245246	218073	199929	184287	152060	114285	-0.4	-2.4	-1.7	-4.7
Freight light duty vehicles	15142	14919	14105	12027	11021	9278	7193	5774	4657	3969	-2.1	-2.6	-4.6	-3.7
Rail	8377	6977	7010	5085	3915	2877	2235	1530	864	428	-3.1	-5.5	-6.1	-12.0
Inland waterway navigation	10168	10209	10740	11454	12250	12748	12494	11740	10414	10128	1.2	1.1	-0.8	-1.5

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B)										EU27: Dominant electricity-battery success with CO2 standards				
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260703**	**277082**	**284476**	**277275**	**296128**	**306553**	**307465**	**314897**	**326215**	**0.9**	**0.4**	**0.4**	**0.6**
Diesel Conventional	87565	101807	104914	85988	58235	44779	32066	17218	8501	5728	-1.7	-6.3	-9.1	-10.4
Diesel Hybrid	0	204	2257	12276	23460	27764	25081	16320	10408	8342	50.6	8.5	-5.2	-6.5
Diesel plug-in hybrid	0	0	748	8830	16519	22154	30419	34026	34634	33840		9.6	4.4	-0.1
Gasoline Conventional	150450	149251	150438	128490	91949	71762	49777	25177	10943	6449	-1.5	-5.7	-9.9	-12.7
Gasoline Hybrid	24	221	2407	16018	31883	38848	36427	25216	17240	14051	53.5	9.3	-4.2	-5.7
Gasoline plug-in hybrid	0	0	711	10599	21225	30136	42703	49021	51960	51054		11.0	5.0	0.4
LPG	4849	8238	13111	17002	17891	20591	19841	13946	9525	8418	7.5	1.9	-3.8	-4.9
CNG	718	976	2476	4979	8081	11491	11777	7944	4709	3395	17.7	8.7	-3.6	-8.1
E85	0	6	17	93	427	744	1007	874	759	722	31.7	23.1	1.6	-1.9
Electric	0	0	4	189	6873	25392	52469	101192	138167	156868		63.3	14.8	4.5
Hydrogen	0	0	0	13	732	2468	4986	16530	28051	37349		68.9	20.9	8.5
2wheelers	**31568**	**33227**	**36238**	**39105**	**41691**	**44072**	**45864**	**46996**	**48368**	**49787**	**1.6**	**1.2**	**0.6**	**0.6**
Gasoline	31568	33227	36238	37985	39084	35834	30373	22197	14955	10227	1.3	-0.6	-4.7	-7.5
Electricity	0	0	0	1121	2607	8238	15491	24799	33413	39561		22.1	11.7	4.8
HDVs, buses and coaches	**8580**	**9479**	**10156**	**10637**	**11010**	**11632**	**12064**	**12445**	**12601**	**12698**	**1.2**	**0.9**	**0.7**	**0.2**
Diesel Conventional	8565	9457	10030	10085	8312	6987	5733	4965	4527	3991	0.6	-3.6	-3.4	-2.2
Diesel Hybrid	0	6	69	429	2467	3929	5063	5582	5359	4988	54.3	24.8	3.6	-1.1
LPG	2	2	12	41	86	161	234	319	394	440	36.8	14.7	7.1	3.3
CNG	13	15	44	81	128	243	343	433	496	528	18.7	11.6	5.9	2.0
Electric	0	0	0	1	17	296	646	1042	1628	2383		87.7	13.4	8.6
Hydrogen	0	0	0	0	0	16	45	104	197	370		103.2	20.6	13.5
Total annual cost excl. disutility (in million Euro'08)	**2421036**	**2603712**	**2804814**	**3059476**	**3286552**	**3467257**	**3650303**	**3847522**	**4039094**	**4160611**	**1.6**	**1.3**	**1.0**	**0.8**
Passenger transport	**1993300**	**2130926**	**2262608**	**2464524**	**2649958**	**2802789**	**2954682**	**3122286**	**3283079**	**3376249**	**1.5**	**1.3**	**1.1**	**0.8**
Public road transport	47158	52715	56135	60110	64861	65816	67374	69844	71183	71746	1.3	0.9	0.6	0.3
Private cars	1590477	1692337	1771672	1911780	2041694	2149760	2263045	2391547	2501339	2545800	1.2	1.2	1.1	0.6
2wheelers	46744	48915	52918	59158	65851	68750	72408	75185	78520	80193	1.9	1.5	0.9	0.6
Passenger light duty vehicles	113667	124439	135302	143667	148677	155281	162185	166139	172935	179357	1.4	0.8	0.7	0.8
Rail	74543	78186	81210	84062	87480	88325	89165	92879	96730	98519	0.7	0.5	0.5	0.6
Aviation	112942	126148	156464	196010	231076	264306	289600	315256	350226	387833	4.5	3.0	1.8	2.1
Inland navigation	7770	8185	8908	9736	10319	10551	10904	11437	12145	12800	1.8	0.8	0.8	1.1
Freight transport	**427736**	**472787**	**542205**	**594952**	**636594**	**664468**	**695621**	**725236**	**756016**	**784362**	**2.3**	**1.1**	**0.9**	**0.8**
Heavy duty vehicles	298800	338403	392572	433308	465507	486187	512172	536600	562702	586479	2.5	1.2	1.0	0.9
Freight light duty vehicles	31420	33154	34518	35560	38895	41564	44242	47211	49581	51193	0.7	1.6	1.3	0.8
Rail	55914	58699	67840	75041	77772	79832	79955	80124	79965	80731	2.5	0.6	0.0	0.1
Inland waterway navigation	41602	42531	47276	51042	54420	56886	59252	61301	63767	65959	1.8	1.1	0.8	0.7
External costs (in million Euro'08) (1)	**447714**	**404190**	**409353**	**417429**	**432728**	**448041**	**450274**	**441977**	**443830**	**447807**	**0.3**	**0.7**	**-0.1**	**0.1**
Disutility costs (in million Euro'08)	**0**	**84**	**31938**	**53033**	**106436**	**77044**	**91499**	**139390**	**146827**	**132436**	**90.5**	**3.8**	**6.1**	**-0.5**
Passenger transport	0	75	14028	37082	85674	56524	65860	108896	106497	84086	85.8	4.3	6.8	-2.6
Freight transport	0	9	17910	15951	20763	20520	25639	30494	40330	48350	111.3	2.6	4.0	4.7
Total costs (incl. disutility and external costs)	**2421036**	**2603797**	**2836752**	**3112509**	**3392988**	**3544301**	**3741802**	**3986912**	**4185922**	**4293047**	**1.8**	**1.3**	**1.2**	**0.7**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: Dominant electricity-battery success with energy efficiency standards **SUMMARY (A)**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6511**	**7072**	**7423**	**7674**	**8170**	**8501**	**8796**	**9049**	**9294**	**1.3**	**1.0**	**0.7**	**0.6**
Public road transport	526	545	563	580	610	627	650	674	688	696	0.6	0.8	0.7	0.3
Private cars	4309	4472	4821	4967	5001	5286	5450	5595	5748	5892	1.1	0.6	0.6	0.5
2wheelers	150	155	166	178	186	195	203	209	214	220	1.4	0.9	0.7	0.5
Passenger light duty vehicles	227	239	259	270	278	295	306	317	326	335	1.2	0.9	0.7	0.6
Rail	461	482	524	566	614	647	685	722	758	782	1.6	1.3	1.1	0.8
Aviation	527	577	700	820	941	1074	1160	1231	1265	1317	3.6	2.7	1.4	0.7
Inland navigation	40	41	40	42	44	46	47	49	51	52	0.3	0.8	0.6	0.6
Freight transport activity (Gtkm)	**2495**	**2664**	**2886**	**3071**	**3226**	**3374**	**3488**	**3597**	**3653**	**3700**	**1.4**	**0.9**	**0.6**	**0.3**
Heavy duty vehicles	1740	1880	2016	2136	2235	2332	2402	2470	2490	2509	1.3	0.9	0.6	0.2
Freight light duty vehicles	60	61	64	64	70	76	80	84	86	89	0.5	1.7	1.0	0.6
Rail	414	440	503	550	582	612	638	663	686	706	2.2	1.1	0.8	0.6
Inland waterway navigation	280	282	303	321	339	355	368	380	391	396	1.3	1.0	0.7	0.4
Final Energy Demand (ktoe)	**362402**	**372960**	**383551**	**371534**	**341763**	**323311**	**294472**	**264174**	**236159**	**215280**	**0.0**	**-1.4**	**-2.0**	**-2.0**
by transport mode														
Passenger transport	**254276**	**258846**	**265313**	**254150**	**231266**	**218118**	**193894**	**168369**	**146234**	**131978**	**-0.2**	**-1.5**	**-2.6**	**-2.4**
Public road transport	5028	5201	5182	4847	4403	3932	3526	3194	2859	2648	-0.7	-2.1	-2.1	-1.9
Private cars	169568	170749	169832	154873	131023	120030	100875	79525	63351	53085	-1.0	-2.5	-4.0	-4.0
2wheelers	7094	7192	7386	7622	7437	6718	6025	4844	3474	2207	0.6	-1.3	-3.2	-7.6
Passenger light duty vehicles	18828	19762	20141	18707	16940	14813	12294	9988	7770	6375	-0.5	-2.3	-3.9	-4.4
Rail	1960	1985	2130	2187	2289	2259	2247	2191	2102	2035	1.0	0.3	-0.3	-0.7
Aviation	49703	51804	58589	63757	66932	68065	66599	66231	64215	63145	2.1	0.7	-0.3	-0.5
Inland navigation	2094	2153	2053	2156	2243	2302	2329	2395	2463	2482	0.0	0.7	0.4	0.4
Freight transport	**108126**	**114114**	**118237**	**117385**	**110497**	**105193**	**100578**	**95805**	**89925**	**83303**	**0.3**	**-1.1**	**-0.9**	**-1.4**
Heavy duty vehicles	92279	98249	101691	101403	94338	89391	84990	80781	75562	69567	0.3	-1.3	-1.0	-1.5
Freight light duty vehicles	5079	5174	5054	4575	4393	3942	3340	2751	2109	1719	-1.2	-1.5	-3.5	-4.6
Rail	7476	7383	8010	7690	7788	7671	7905	7791	7676	7437	0.4	0.0	0.2	-0.5
Inland waterway navigation	3292	3308	3483	3717	3978	4189	4343	4483	4578	4580	1.2	1.2	0.7	0.2
by fuel														
Oil products	**352414**	**353487**	**355534**	**329482**	**290960**	**260807**	**225443**	**183398**	**138216**	**107968**	**-0.7**	**-2.3**	**-3.5**	**-5.2**
Gasoline	114297	106545	101671	87888	70942	58488	45879	31725	20852	13990	-1.9	-4.0	-5.9	-7.9
Diesel	182919	188834	185219	164756	139497	119715	103901	86202	67571	51089	-1.4	-3.1	-3.2	-5.1
Kerosene	49703	51804	58589	63757	66932	67676	64449	58556	45632	39429	2.1	0.6	-1.4	-3.9
Liquefied Petroleum Gas	4520	5387	9212	12283	12832	14225	10591	6378	3711	3027	8.6	1.5	-7.7	-7.2
Residual fuel oil	974	916	843	798	757	702	623	537	450	433	-1.4	-1.3	-2.7	-2.1
Biofuels	**3129**	**11984**	**18211**	**28520**	**32183**	**35892**	**37781**	**44705**	**56556**	**60814**	**9.1**	**2.3**	**2.2**	**3.1**
Bio Gasoline	581	3338	5101	7964	8419	9108	9039	9518	8609	6869	9.1	1.4	0.4	-3.2
Bio Diesel	2548	8646	13109	20556	23764	26343	26500	27347	29042	29585	9.0	2.5	0.4	0.8
Bio Kerosene	0	0	0	0	0	389	2150	7674	18584	23715			34.7	11.9
DME	0	0	0	0	1	3	3	3	4	6	3.9	26.7	0.9	6.9
Bio Heavy	0	0	0	0	0	8	43	91	157	169			27.7	6.3
Biogas	0	0	0	0	0	41	45	71	161	469	41.0	111.6	5.6	20.7
Electricity	6353	6780	7702	9388	12038	16224	22053	29008	35532	40797	**3.3**	**5.6**	**6.0**	**3.5**
Natural Gas	506	710	2104	4141	6387	9679	7731	4721	3020	2193	**19.3**	**8.9**	**-6.9**	**-7.4**
Hydrogen	0	0	0	3	195	709	1464	2342	2835	3509		**71.1**	**12.7**	**4.1**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.5**	**34.2**	**30.1**	**26.7**	**22.8**	**19.1**	**16.2**	**14.2**	**-1.5**	**-2.5**	**-3.3**	**-2.9**
Public road transport	9.6	9.5	9.2	8.4	7.2	6.3	5.4	4.7	4.2	3.8	-1.3	-2.8	-2.8	-2.2
Private cars	39.4	38.2	35.2	31.2	26.2	22.7	18.5	14.2	11.0	9.0	-2.0	-3.1	-4.6	-4.5
2wheelers	47.3	46.4	44.5	42.9	39.9	34.4	29.7	23.2	16.2	10.0	-0.8	-2.2	-3.9	-8.0
Passenger light duty vehicles	82.8	82.7	77.9	69.2	61.0	50.1	40.2	31.5	23.8	19.0	-1.8	-3.2	-4.5	-4.9
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.1	63.4	57.4	53.8	50.8	47.9	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.5	49.7	49.3	48.6	47.9	-0.3	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**41.0**	**38.2**	**34.2**	**31.2**	**28.8**	**26.6**	**24.6**	**22.5**	**-1.1**	**-2.0**	**-1.6**	**-1.7**
Heavy duty vehicles	53.0	52.3	50.4	47.5	42.2	38.3	35.4	32.7	30.3	27.7	-1.0	-2.1	-1.6	-1.6
Freight light duty vehicles	84.8	84.4	79.5	71.0	63.1	51.9	41.7	32.8	24.4	19.4	-1.7	-3.1	-4.5	-5.2
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.7	11.2	10.5	-1.8	-1.1	-0.7	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.8	11.7	11.6	-0.1	0.2	0.0	-0.2
CO_2 EMISSIONS (in ktons CO_2)	**1053078**	**1057753**	**1065789**	**991380**	**881240**	**798193**	**689644**	**558815**	**420804**	**328295**	**-0.6**	**-2.1**	**-3.5**	**-5.2**
Passenger transport	740076	737556	742888	687039	608047	551744	467975	362302	260670	202339	-0.7	-2.2	-4.1	-5.7
Public road transport	15225	15249	14809	13336	11695	9665	7801	6347	4881	4082	-1.3	-3.2	-4.1	-4.3
Private cars	493354	483807	470546	407842	328432	283031	221308	147008	96368	64540	-1.7	-3.6	-6.3	-7.9
2wheelers	20311	20134	20334	20336	19657	16518	14265	10231	6368	3434	0.1	-2.1	-4.7	-10.3
Passenger light duty vehicles	56340	57220	56395	49248	42423	34508	26563	18655	12085	7883	-1.5	-3.5	-6.0	-8.3
Rail	1085	967	814	649	532	400	269	146	51	5	-3.9	-4.7	-9.6	-28.5
Aviation	147321	153548	173658	188976	198385	200592	191026	173561	135252	116869	2.1	0.6	-1.4	-3.9
Inland navigation	6439	6631	6330	6650	6924	7030	6744	6353	5665	5527	0.0	0.6	-1.0	-1.4
Freight transport	313002	320197	322901	304341	273193	246450	221668	196513	160134	125957	**-0.5**	**-2.1**	**-2.2**	**-4.4**
Heavy duty vehicles	279315	288093	291047	275761	246012	221612	199682	178053	145567	113278	-0.4	-2.2	-2.2	-4.4
Freight light duty vehicles	15142	14919	14104	12041	11016	9212	7257	5179	3274	2115	-2.1	-2.6	-5.6	-8.6
Rail	8377	6977	7010	5085	3914	2878	2235	1531	865	428	-3.1	-5.5	-6.1	-12.0
Inland waterway navigation	10168	10209	10740	11454	12250	12748	12494	11751	10428	10136	1.2	1.1	-0.8	-1.5

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B)						EU27: Dominant electricity-battery success with energy efficiency standards								
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260703**	**277082**	**285043**	**277376**	**295412**	**305925**	**314246**	**323599**	**333389**	**0.9**	**0.4**	**0.6**	**0.6**
Diesel Conventional	87565	101807	104914	87056	58632	44070	25602	9917	2192	418	-1.6	-6.6	-13.9	-27.1
Diesel Hybrid	0	204	2257	11807	23437	28494	35038	33215	24917	15938	50.0	9.2	1.5	-7.1
Diesel plug-in hybrid	0	0	748	8022	16084	22370	31758	44638	53243	56447		10.8	7.2	2.4
Gasoline Conventional	150450	149251	150438	130597	92599	69772	39378	14670	2828	455	-1.3	-6.1	-14.4	-29.3
Gasoline Hybrid	24	221	2407	15227	31765	39769	48765	46875	35486	22061	52.7	10.1	1.7	-7.3
Gasoline plug-in hybrid	0	0	711	9923	20990	30715	43271	57703	65791	67382		12.0	6.5	1.6
LPG	4849	8238	13111	17127	17658	19457	14682	7605	2677	946	7.6	1.3	-9.0	-18.8
CNG	718	976	2476	5004	8009	11124	8865	4479	1424	361	17.8	8.3	-8.7	-22.3
E85	0	6	17	85	424	749	1062	801	452	184	30.6	24.3	0.7	-13.7
Electric	0	0	4	182	7030	26341	52955	87946	127849	162964		64.5	12.8	6.4
Hydrogen	0	0	0	12	747	2552	4549	6398	6741	6234		70.6	9.6	-0.3
2wheelers	**31568**	**33227**	**36238**	**39415**	**41982**	**44287**	**46305**	**47432**	**48555**	**49642**	**1.7**	**1.2**	**0.7**	**0.5**
Gasoline	31568	33227	36238	39408	41647	39135	37202	30069	20871	11029	1.7	-0.1	-2.6	-9.5
Electricity	0	0	0	6	335	5152	9103	17363	27685	38613		95.0	12.9	8.3
HDVs, buses and coaches	**8580**	**9479**	**10157**	**10613**	**10980**	**11609**	**12045**	**12418**	**12565**	**12667**	**1.1**	**0.9**	**0.7**	**0.2**
Diesel Conventional	8565	9457	9966	9699	7801	6524	5321	4396	3946	3462	0.3	-3.9	-3.9	-2.4
Diesel Hybrid	0	6	135	826	3005	4419	5454	6040	5758	5310	64.8	18.3	3.2	-1.3
LPG	2	2	12	32	68	142	211	282	351	398	33.5	16.1	7.0	3.5
CNG	13	15	44	44	57	171	262	336	395	429	11.7	14.5	7.0	2.5
Electric	0	0	0	12	49	336	749	1253	1907	2686		40.1	14.1	7.9
Hydrogen	0	0	0	0	0	16	47	112	207	383		83.2	21.1	13.1
Total annual cost excl. disutility (in million Euro'08)	**2421036**	**2603712**	**2804693**	**3058655**	**3286335**	**3468520**	**3655694**	**3819144**	**3974122**	**4092205**	**1.6**	**1.3**	**1.0**	**0.7**
Passenger transport	**1993300**	**2130926**	**2262608**	**2463996**	**2649917**	**2804190**	**2960338**	**3094289**	**3217643**	**3307340**	**1.5**	**1.3**	**1.0**	**0.7**
Public road transport	47158	52715	56135	60161	64868	65691	67213	68729	69874	70697	1.3	0.9	0.5	0.3
Private cars	1590477	1692337	1771671	1911506	2042348	2152516	2270562	2360687	2430393	2470092	1.2	1.2	0.9	0.5
2wheelers	46744	48915	52918	58699	65124	67796	71021	74417	78528	80884	1.8	1.5	0.9	0.8
Passenger light duty vehicles	113667	124439	135302	143807	148606	154839	161655	169865	178394	185105	1.5	0.7	0.9	0.9
Rail	74543	78186	81210	83907	87468	88468	89380	91791	95540	97457	0.7	0.5	0.4	0.6
Aviation	112942	126148	156464	196127	231123	264269	289551	317431	352867	390391	4.5	3.0	1.8	2.1
Inland navigation	7770	8185	8908	9789	10380	10611	10957	11369	12048	12714	1.8	0.8	0.7	1.1
Freight transport	**427736**	**472787**	**542085**	**594659**	**636418**	**664330**	**695356**	**724856**	**756479**	**784865**	**2.3**	**1.1**	**0.9**	**0.8**
Heavy duty vehicles	298800	338403	392456	433033	465325	486045	511921	536125	562822	586528	2.5	1.2	1.0	0.9
Freight light duty vehicles	31420	33154	34516	35549	38890	41567	44224	47160	49675	51500	0.7	1.6	1.3	0.9
Rail	55914	58699	67839	75037	77782	79832	79955	80211	80111	80827	2.5	0.6	0.0	0.1
Inland waterway navigation	41602	42531	47275	51039	54422	56886	59257	61359	63871	66010	1.8	1.1	0.8	0.7
External costs (in million Euro'08) (1)	**447714**	**404190**	**409226**	**416575**	**430951**	**445994**	**448780**	**452424**	**453534**	**453768**	**0.3**	**0.7**	**0.1**	**0.0**
Disutility costs (in million Euro'08)	**0**	**84**	**31827**	**53398**	**112314**	**84095**	**94695**	**98096**	**107656**	**101469**	**90.6**	**4.6**	**1.6**	**0.3**
Passenger transport	0	75	14029	37817	91538	63477	68959	69224	68067	54753	86.2	5.3	0.9	-2.3
Freight transport	0	9	17798	15581	20776	20618	25736	28872	39588	46716	110.8	2.8	3.4	4.9
Total costs (incl. disutility and external costs)	**2421036**	**2603797**	**2836520**	**3112053**	**3398649**	**3552615**	**3750389**	**3917240**	**4081778**	**4193674**	**1.8**	**1.3**	**1.0**	**0.7**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: GTL-High BTL **SUMMARY (A)**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	6240	6512	7076	7429	7685	8123	8444	8654	8810	8867	1.3	0.9	0.6	0.2
Public road transport	526	545	563	597	624	634	649	666	677	683	0.9	0.6	0.5	0.3
Private cars	4309	4472	4824	4957	4999	5238	5403	5476	5540	5513	1.0	0.6	0.4	0.1
2wheelers	150	155	166	175	184	194	201	204	205	205	1.2	1.0	0.5	0.0
Passenger light duty vehicles	227	239	259	271	278	293	303	310	314	313	1.2	0.8	0.6	0.1
Rail	461	482	524	567	614	648	685	725	766	799	1.6	1.3	1.1	1.0
Aviation	527	578	701	821	942	1071	1156	1226	1259	1304	3.6	2.7	1.4	0.6
Inland navigation	40	41	40	42	44	45	46	47	49	49	0.2	0.8	0.5	0.3
Freight transport activity (Gtkm)	2495	2664	2885	3073	3230	3370	3483	3572	3619	3614	1.4	0.9	0.6	0.1
Heavy duty vehicles	1740	1880	2016	2139	2241	2329	2400	2449	2463	2426	1.3	0.9	0.5	-0.1
Freight light duty vehicles	60	61	64	64	69	74	77	80	81	80	0.5	1.4	0.8	0.1
Rail	414	440	503	549	582	612	638	664	687	713	2.2	1.1	0.8	0.7
Inland waterway navigation	280	282	303	320	338	355	367	379	388	394	1.3	1.0	0.7	0.4
Final Energy Demand (ktoe)	362402	373100	384351	373231	347801	335626	320475	300809	285287	268946	0.0	-1.1	-1.1	-1.1
by transport mode														
Passenger transport	254276	258985	265801	255020	237025	230652	220408	205719	195845	186744	-0.2	-1.0	-1.1	-1.0
Public road transport	5028	5200	5182	5128	4763	4343	4036	3771	3509	3271	-0.1	-1.6	-1.4	-1.4
Private cars	169568	170764	170129	155333	135687	129732	122431	109485	103246	97303	-0.9	-1.8	-1.7	-1.2
2wheelers	7094	7192	7387	7335	7139	7126	6914	6649	6134	5656	0.2	-0.3	-0.7	-1.6
Passenger light duty vehicles	18828	19763	20170	18965	17837	16943	16005	15161	14322	13185	-0.4	-1.1	-1.1	-1.4
Rail	1960	1985	2130	2190	2289	2260	2250	2196	2124	2080	1.0	0.3	-0.3	-0.5
Aviation	49703	51932	58754	63931	67089	67972	66475	66131	64163	62957	2.1	0.6	-0.3	-0.5
Inland navigation	2094	2149	2050	2138	2221	2276	2296	2324	2348	2292	-0.1	0.6	0.2	-0.1
Freight transport	108126	114116	118550	118211	110775	104974	100067	95090	89442	82202	0.4	-1.2	-1.0	-1.4
Heavy duty vehicles	92279	98251	101997	102181	94466	88712	83630	78809	73444	66745	0.4	-1.4	-1.2	-1.6
Freight light duty vehicles	5079	5174	5059	4626	4560	4414	4216	4054	3834	3518	-1.1	-0.5	-0.8	-1.4
Rail	7476	7383	8010	7687	7780	7670	7900	7792	7678	7489	0.4	0.0	0.2	-0.4
Inland waterway navigation	3292	3308	3483	3717	3969	4179	4322	4435	4486	4450	1.2	1.2	0.6	0.0
by fuel														
Oil products	352414	353627	356345	330493	296266	264667	232298	190732	142401	99191	-0.7	-2.2	-3.2	-6.3
Gasoline	114297	106556	101851	87762	74009	65936	57023	44541	33160	23451	-1.9	-2.8	-3.8	-6.2
Diesel	182919	188837	185747	165927	141027	114369	93270	71778	49140	26743	-1.3	-3.7	-4.6	-9.4
Kerosene	49703	51932	58754	63931	67089	67575	64275	58239	44944	34055	2.1	0.6	-1.5	-5.2
Liquified Petroleum Gas	4520	5386	9151	12076	13386	16085	17118	15680	14814	14646	8.4	2.9	-0.3	-0.7
Residual fuel oil	974	916	842	796	755	702	611	494	344	295	-1.4	-1.2	-3.5	-5.0
Biofuels	3129	11984	18260	29652	34395	49631	64135	83550	113991	137411	9.5	5.3	5.3	5.1
Bio Gasoline	581	3338	5110	8168	9045	12106	16555	23096	29997	34197	9.4	4.0	6.7	4.0
Bio Diesel	2548	8646	13149	21478	25257	35354	43246	49508	59465	62049	9.5	5.1	3.4	2.3
Bio Kerosene	0	0	0	0	0	396	2199	7892	19219	28901			34.9	13.9
DME	0	0	1	4	56	1030	1309	2233	4467	11277	36.3	72.6	8.0	17.6
Bio Heavy	0	0	0	0	0	9	58	143	285	350			31.7	9.4
Biogas	0	0	0	1	37	736	767	677	558	637	105.8	93.4	-0.8	-0.6
Electricity	6353	6780	7642	8876	10237	11461	12633	14238	14638	14962	2.7	2.6	2.2	0.5
Natural Gas	506	710	2103	4210	6817	9546	10715	10675	11750	13573	19.5	8.5	1.1	2.4
Hydrogen	0	0	0	0	86	320	694	1615	2507	3809		104.5	17.6	9.0
Vehicles efficiency														
Passenger transport (toe/Mpkm)	40.7	39.8	37.6	34.3	30.8	28.4	26.1	23.8	22.2	21.1	-1.5	-1.9	-1.8	-1.2
Public road transport	9.6	9.5	9.2	8.6	7.6	6.9	6.2	5.7	5.2	4.8	-1.0	-2.2	-1.9	-1.7
Private cars	39.4	38.2	35.3	31.3	27.1	24.8	22.7	20.0	18.6	17.6	-2.0	-2.3	-2.1	-1.2
2wheelers	47.3	46.4	44.5	41.9	38.7	36.7	34.4	32.6	29.9	27.6	-1.0	-1.3	-1.2	-1.6
Passenger light duty vehicles	82.8	82.7	78.0	70.1	64.2	57.9	52.7	48.9	45.6	42.1	-1.6	-1.9	-1.7	-1.5
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.0	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.2	63.5	57.5	53.9	51.0	48.3	-1.4	-2.0	-1.6	-1.1
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.4	49.6	49.0	48.1	46.9	-0.3	-0.2	-0.3	-0.4
Freight transport activity (toe/Mtkm)	43.3	42.8	41.1	38.5	34.3	31.2	28.7	26.6	24.7	22.7	-1.1	-2.1	-1.6	-1.6
Heavy duty vehicles	53.0	52.3	50.6	47.8	42.2	38.1	34.8	32.2	29.8	27.5	-0.9	-2.2	-1.7	-1.6
Freight light duty vehicles	84.8	84.4	79.6	71.9	66.2	59.9	54.7	50.8	47.4	43.7	-1.6	-1.8	-1.6	-1.5
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.7	11.2	10.5	-1.8	-1.1	-0.7	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.7	11.6	11.3	-0.1	0.2	-0.1	-0.3
CO$_2$ EMISSIONS (in ktons CO$_2$)	1053078	1058168	1068251	994753	897727	807796	713154	589830	448221	322785	-0.6	-2.1	-3.1	-5.9
Passenger transport	740076	737965	744456	688083	624601	571603	514777	425797	325137	244625	-0.7	-1.8	-2.9	-5.4
Public road transport	15225	15245	14810	14128	12692	10542	8756	6961	5130	3688	-0.8	-2.9	-4.1	-6.2
Private cars	493354	483850	471539	407999	342265	297917	259772	199719	151795	115054	-1.7	-3.1	-3.9	-5.4
2wheelers	20311	20135	20337	19517	18732	17446	15810	13482	10788	8371	-0.3	-1.1	-2.5	-4.7
Passenger light duty vehicles	56340	57223	56491	49705	44675	38132	33250	27390	20264	13544	-1.4	-2.6	-3.3	-6.8
Rail	1085	966	814	649	532	393	256	129	41	3	-3.9	-4.9	-10.6	-30.8
Aviation	147321	153926	174147	189492	198851	200293	190512	172621	133214	100940	2.1	0.6	-1.5	-5.2
Inland navigation	6439	6619	6319	6595	6854	6880	6421	5495	3905	3024	0.0	0.4	-2.2	-5.8
Freight transport	313002	320202	323795	306669	273125	236193	198376	164034	123084	78161	-0.4	-2.6	-3.6	-7.1
Heavy duty vehicles	279315	288098	291922	277997	245549	210761	175421	144947	109633	68562	-0.4	-2.7	-3.7	-7.2
Freight light duty vehicles	15142	14919	14123	12135	11442	10036	8869	7461	5602	3791	-2.0	-1.9	-2.9	-6.5
Rail	8377	6977	7010	5085	3913	2838	2123	1355	702	296	-3.1	-5.7	-7.1	-14.1
Inland waterway navigation	10168	10209	10740	11452	12222	12557	11964	10270	7148	5511	1.2	0.9	-2.0	-6.0

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B)														**EU27: GTL-High BTL**
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**'10-'20**	**'20-'30**	**'30-'40**	**'40-'50**
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260716**	**277176**	**284863**	**277458**	**293528**	**303359**	**307702**	**311110**	**311053**	**0.9**	**0.3**	**0.5**	**0.1**
Diesel Conventional	87565	101815	105372	87416	62776	52168	45914	37041	33955	33787	-1.5	-5.0	-3.4	-0.9
Diesel Hybrid	0	204	2281	14892	28092	34168	35989	34516	36665	37122	53.6	8.7	0.1	0.7
Diesel plug-in hybrid	0	0	395	5531	8924	10998	12317	17946	18913	17557		7.1	5.0	-0.2
Gasoline Conventional	150450	149260	150838	130371	99364	86781	76581	58676	50926	50849	-1.3	-4.0	-3.8	-1.4
Gasoline Hybrid	24	221	2422	18790	38107	50817	59538	71074	73707	68460	56.0	10.5	3.4	-0.4
Gasoline plug-in hybrid	0	0	357	5902	10396	13965	16680	23095	24946	24454		9.0	5.2	0.6
LPG	4849	8234	13033	16773	18364	22609	25226	23751	22686	23058	7.4	3.0	0.5	-0.3
CNG	718	976	2459	4983	8642	13323	16020	16599	18294	21698	17.7	10.3	2.2	2.7
E85	0	6	17	124	706	2227	4076	7369	9105	8464	35.6	33.5	12.7	1.4
Electric	0	0	2	80	1760	5434	9054	13329	15714	17473		52.4	9.4	2.7
Hydrogen	0	0	0	1	327	1039	1965	4307	6201	8130		102.4	15.3	6.6
2wheelers	**31568**	**33229**	**36243**	**38778**	**41397**	**43972**	**45847**	**46709**	**46880**	**46873**	**1.6**	**1.3**	**0.6**	**0.0**
Gasoline	31568	33229	36243	37722	39830	41783	43028	42912	40938	39263	1.3	1.0	0.3	-0.9
Electricity	0	0	0	1057	1567	2189	2820	3798	5942	7610		7.6	5.7	7.2
HDVs, buses and coaches	**8580**	**9479**	**10157**	**10645**	**11017**	**11612**	**12033**	**12323**	**12426**	**12369**	**1.2**	**0.9**	**0.6**	**0.0**
Diesel Conventional	8565	9457	10033	10105	8358	7144	6022	5318	4986	4496	0.7	-3.4	-2.9	-1.7
Diesel Hybrid	0	6	68	422	2446	4017	5304	5974	6007	5860	54.1	25.3	4.0	-0.2
LPG	2	2	12	40	84	157	226	313	406	517	36.3	14.8	7.1	5.1
CNG	13	15	44	78	119	188	260	350	477	671	18.3	9.1	6.4	6.7
Electric	0	0	0	0	10	94	188	288	391	527		74.7	11.8	6.2
Hydrogen	0	0	0	0	0	12	32	79	160	299		121.8	20.4	14.2
Total annual cost excl. disutility (in million Euro'08)	**2420990**	**2603530**	**2804435**	**3057341**	**3289605**	**3482918**	**3639268**	**3794924**	**3952585**	**4108106**	**1.6**	**1.3**	**0.9**	**0.8**
Passenger transport	**1993254**	**2130739**	**2262216**	**2462858**	**2653827**	**2817770**	**2943046**	**3064831**	**3188566**	**3303046**	**1.5**	**1.4**	**0.8**	**0.8**
Public road transport	47158	52701	56112	60039	64873	66372	68082	70088	72036	74013	1.3	1.0	0.5	0.5
Private cars	1590431	1692455	1771588	1909009	2041843	2157928	2243792	2323061	2393774	2458404	1.2	1.2	0.7	0.6
2wheelers	46744	48916	52925	60076	67472	70531	73967	77824	82952	86370	2.1	1.6	1.0	1.0
Passenger light duty vehicles	113667	124450	135350	144360	151412	161149	169684	176903	186060	195421	1.5	1.1	0.9	1.0
Rail	74543	78191	81200	84010	87445	88619	89325	92299	96687	100036	0.7	0.5	0.4	0.8
Aviation	112942	125854	156149	195660	230477	262573	287233	313166	344748	375538	4.5	3.0	1.8	1.8
Inland navigation	7770	8172	8892	9705	10305	10598	10963	11490	12309	13262	1.7	0.9	0.8	1.4
Freight transport	**427736**	**472791**	**542218**	**594482**	**635778**	**665147**	**696222**	**730093**	**764018**	**805060**	**2.3**	**1.1**	**0.9**	**1.0**
Heavy duty vehicles	298800	338407	392583	432911	464524	485881	511813	540012	568456	601946	2.5	1.2	1.1	1.1
Freight light duty vehicles	31420	33153	34518	35589	39155	42333	45039	47772	50416	52960	0.7	1.8	1.2	1.0
Rail	55914	58699	67841	74977	77719	79898	79991	80416	80363	81812	2.5	0.6	0.1	0.2
Inland waterway navigation	41602	42531	47277	51005	54380	57034	59379	61892	64782	68342	1.8	1.1	0.8	1.0
External costs (in million Euro'08) (1)	**447714**	**404222**	**409576**	**418572**	**434885**	**450797**	**460194**	**466397**	**472348**	**469674**	**0.3**	**0.7**	**0.3**	**0.1**
Disutility costs (in million Euro'08)	**0**	**186**	**30952**	**50752**	**108139**	**96560**	**106548**	**139537**	**186508**	**257446**	**75.2**	**6.6**	**3.8**	**6.3**
Passenger transport	0	183	13055	35593	88101	74596	79787	104387	134433	178339	69.4	7.7	3.4	5.5
Freight transport	0	4	17896	15159	20038	21964	26761	35150	52075	79108	130.2	3.8	4.8	8.4
Total costs (incl. disutility and external costs)	**2420990**	**2603716**	**2835386**	**3108093**	**3397744**	**3579478**	**3745816**	**3934462**	**4139093**	**4365552**	**1.8**	**1.4**	**1.0**	**1.0**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model

EU27: GTL-Biomass constraint **SUMMARY (A)**

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'10-'20	'20-'30	'30-'40	'40-'50
											Annual % Change			
Transport activity														
Passenger transport activity (Gpkm)	**6240**	**6512**	**7064**	**7389**	**7591**	**7942**	**8120**	**8329**	**8239**	**8034**	**1.3**	**0.7**	**0.5**	**-0.4**
Public road transport	526	545	564	599	628	643	666	687	717	746	0.9	0.7	0.7	0.8
Private cars	4309	4472	4812	4916	4903	5053	5096	5170	5032	4752	1.0	0.3	0.2	-0.8
2wheelers	150	155	166	175	184	193	199	203	204	204	1.2	1.0	0.5	0.0
Passenger light duty vehicles	227	239	258	269	276	289	297	304	300	291	1.2	0.7	0.5	-0.4
Rail	461	482	524	569	618	656	702	743	805	861	1.7	1.4	1.3	1.5
Aviation	527	578	700	819	938	1062	1112	1171	1129	1126	3.6	2.6	1.0	-0.4
Inland navigation	40	41	40	42	44	46	48	49	53	56	0.3	0.9	0.8	1.2
Freight transport activity (Gtkm)	**2495**	**2664**	**2883**	**3067**	**3210**	**3345**	**3450**	**3519**	**3528**	**3515**	**1.4**	**0.9**	**0.5**	**0.0**
Heavy duty vehicles	1740	1880	2013	2132	2216	2297	2357	2376	2333	2275	1.3	0.7	0.3	-0.4
Freight light duty vehicles	60	61	64	64	69	73	77	80	79	79	0.5	1.3	0.8	-0.1
Rail	414	440	503	550	585	616	644	675	708	739	2.3	1.1	0.9	0.9
Inland waterway navigation	280	282	304	321	341	358	372	389	408	421	1.3	1.1	0.8	0.8
Final Energy Demand (ktoe)	**362402**	**373100**	**383756**	**371575**	**344089**	**329627**	**310459**	**291149**	**268005**	**246390**	**0.0**	**-1.2**	**-1.2**	**-1.7**
by transport mode														
Passenger transport	**254276**	**258985**	**265323**	**253659**	**234250**	**225787**	**211846**	**198004**	**181624**	**167228**	**-0.2**	**-1.2**	**-1.3**	**-1.7**
Public road transport	5028	5200	5187	5142	4793	4396	4129	3899	3742	3611	-0.1	-1.6	-1.2	-0.8
Private cars	169568	170764	169721	154166	133277	125518	116306	104392	94911	85280	-1.0	-2.0	-1.8	-2.0
2wheelers	7094	7192	7386	7333	7128	7100	6864	6636	6127	5721	0.2	-0.3	-0.7	-1.5
Passenger light duty vehicles	18828	19763	20146	18907	17740	16789	15745	14992	13963	12779	-0.4	-1.2	-1.1	-1.6
Rail	1960	1985	2132	2196	2303	2279	2307	2242	2228	2238	1.0	0.4	-0.2	0.0
Aviation	49703	51932	58699	63776	66780	67408	64124	63413	58049	54931	2.1	0.6	-0.6	-1.4
Inland navigation	2094	2149	2051	2141	2229	2296	2372	2430	2604	2668	0.0	0.7	0.6	0.9
Freight transport	**108126**	**114116**	**118433**	**117916**	**109839**	**103841**	**98612**	**93146**	**86381**	**79162**	**0.3**	**-1.3**	**-1.1**	**-1.6**
Heavy duty vehicles	92279	98251	101876	101873	93472	87494	82048	76601	69882	62960	0.4	-1.5	-1.3	-1.9
Freight light duty vehicles	5079	5174	5059	4627	4559	4418	4228	4095	3856	3631	-1.1	-0.5	-0.8	-1.2
Rail	7476	7383	8014	7696	7813	7714	7964	7892	7898	7752	0.4	0.0	0.2	-0.2
Inland waterway navigation	3292	3308	3484	3719	3995	4215	4371	4557	4744	4819	1.2	1.3	0.8	0.6
by fuel														
Oil products	**352414**	**353627**	**355773**	**328970**	**294021**	**261098**	**229522**	**190305**	**146017**	**102491**	**-0.7**	**-2.3**	**-3.1**	**-6.0**
Gasoline	114297	106556	101567	87003	72841	64195	55583	44220	35255	27449	-2.0	-3.0	-3.7	-4.7
Diesel	182919	188837	185527	165360	140360	113377	94604	74724	56201	31518	-1.3	-3.7	-4.1	-8.3
Kerosene	49703	51932	58699	63776	66780	67015	62002	55845	40660	30625	2.1	0.5	-1.8	-5.8
Liquefied Petroleum Gas	4520	5386	9137	12035	13283	15805	16702	14990	13475	12549	8.4	2.8	-0.5	-1.8
Residual fuel oil	974	916	842	796	757	706	631	525	425	351	-1.4	-1.2	-2.9	-4.0
Biofuels	**3129**	**11984**	**18228**	**29503**	**32910**	**47536**	**57592**	**75994**	**96219**	**117478**	**9.4**	**4.9**	**4.8**	**4.5**
Bio Gasoline	581	3338	5096	8095	8474	10873	13778	19474	22927	24342	9.3	3.0	6.0	2.3
Bio Diesel	2548	8646	13131	21401	24331	34108	38659	44667	48463	53064	9.5	4.8	2.7	1.7
Bio Kerosene	0	0	0	0	0	393	2122	7568	17388	24306			34.4	12.4
DME	0	0	1	5	64	1187	1827	2819	5569	13170	37.7	73.3	9.0	16.7
Bio Heavy	0	0	0	0	0	8	48	122	223	311			30.8	9.8
Biogas	0	0	0	1	42	966	1158	1344	1649	2283	107.8	96.9	3.4	5.4
Electricity	6353	6780	7649	8897	10292	11516	12653	14003	14367	14414	**2.8**	**2.6**	**2.0**	**0.3**
Natural Gas	506	710	2106	4205	6779	9161	10026	9399	9314	9193	**19.5**	**8.1**	**0.3**	**-0.2**
Hydrogen	0	0	0	0	87	317	666	1450	2088	2815		**104.2**	**16.4**	**6.9**
Vehicles efficiency														
Passenger transport (toe/Mpkm)	**40.7**	**39.8**	**37.6**	**34.3**	**30.9**	**28.4**	**26.1**	**23.8**	**22.0**	**20.8**	**-1.5**	**-1.9**	**-1.8**	**-1.3**
Public road transport	9.6	9.5	9.2	8.6	7.6	6.8	6.2	5.7	5.2	4.8	-1.1	-2.3	-1.8	-1.6
Private cars	39.4	38.2	35.3	31.4	27.2	24.8	22.8	20.2	18.9	17.9	-2.0	-2.3	-2.1	-1.2
2wheelers	47.3	46.4	44.5	41.9	38.8	36.8	34.5	32.6	30.0	28.0	-1.0	-1.3	-1.2	-1.5
Passenger light duty vehicles	82.8	82.7	78.0	70.2	64.3	58.0	53.0	49.4	46.6	43.9	-1.6	-1.9	-1.6	-1.2
Rail	4.3	4.1	4.1	3.9	3.7	3.5	3.3	3.0	2.8	2.6	-0.6	-1.1	-1.4	-1.5
Aviation	94.3	89.8	83.8	77.8	71.2	63.5	57.7	54.1	51.4	48.8	-1.4	-2.0	-1.6	-1.0
Inland navigation	53.0	52.8	51.6	51.3	50.9	50.4	49.8	49.3	48.9	48.0	-0.3	-0.2	-0.2	-0.3
Freight transport activity (toe/Mtkm)	**43.3**	**42.8**	**41.1**	**38.4**	**34.2**	**31.0**	**28.6**	**26.5**	**24.5**	**22.5**	**-1.1**	**-2.1**	**-1.6**	**-1.6**
Heavy duty vehicles	53.0	52.3	50.6	47.8	42.2	38.1	34.8	32.2	30.0	27.7	-0.9	-2.2	-1.7	-1.5
Freight light duty vehicles	84.8	84.4	79.6	72.0	66.4	60.1	55.1	51.3	48.5	45.8	-1.6	-1.8	-1.6	-1.1
Rail	18.1	16.8	15.9	14.0	13.4	12.5	12.4	11.7	11.2	10.5	-1.8	-1.1	-0.7	-1.1
Inland waterway navigation	11.7	11.7	11.5	11.6	11.7	11.8	11.8	11.7	11.6	11.4	-0.1	0.2	0.0	-0.2
CO_2 EMISSIONS (in ktons CO_2)	**1053078**	**1058168**	**1066569**	**990253**	**891062**	**796511**	**703809**	**586154**	**454253**	**323302**	**-0.7**	**-2.2**	**-3.0**	**-5.8**
Passenger transport	740076	737965	743113	684411	619113	558908	497380	414503	316868	236752	-0.8	-2.0	-2.9	-5.4
Public road transport	15225	15245	14825	14165	12824	10819	9327	7614	6218	4248	-0.7	-2.7	-3.5	-5.7
Private cars	493354	483850	470407	404895	337519	286430	247689	193041	150713	112037	-1.8	-3.4	-3.9	-5.3
2wheelers	20311	20135	20335	19511	18785	17634	16289	14169	11867	9537	-0.3	-1.0	-2.2	-3.9
Passenger light duty vehicles	56340	57223	56425	49554	44639	38061	33329	28045	22364	16081	-1.4	-2.6	-3.0	-5.4
Rail	1085	966	814	649	532	392	261	132	46	4	-3.9	-4.9	-10.3	-29.9
Aviation	147321	153926	173985	189032	197935	198633	183775	165525	120518	90772	2.1	0.5	-1.8	-5.8
Inland navigation	6439	6619	6322	6604	6879	6938	6710	5976	5143	4074	0.0	0.5	-1.5	-3.8
Freight transport	313002	320202	323456	305842	271949	237603	206429	171651	137385	86550	**-0.5**	**-2.5**	**-3.2**	**-6.6**
Heavy duty vehicles	279315	288098	291579	277158	244237	211968	182936	151449	121177	74488	-0.4	-2.6	-3.3	-6.9
Freight light duty vehicles	15142	14919	14122	12138	11491	10124	9073	7806	6350	4786	-2.0	-1.8	-2.6	-4.8
Rail	8377	6977	7013	5088	3918	2849	2186	1408	813	350	-3.1	-5.6	-6.8	-13.0
Inland waterway navigation	10168	10209	10743	11458	12302	12662	12234	10988	9044	6925	1.2	1.0	-1.4	-4.5

Source: PRIMES-TREMOVE Transport Model

SUMMARY (B)														**EU27: GTL-Biomass constraint**
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**'10-'20**	**'20-'30**	**'30-'40**	**'40-'50**
											Annual % Change			
Total stock per category and per fuel (in thousand vehicles)														
Private cars and LDVs	**243605**	**260716**	**276700**	**283146**	**273358**	**285565**	**289785**	**293217**	**288531**	**276265**	**0.8**	**0.1**	**0.3**	**-0.6**
Diesel Conventional	87565	101815	105236	87066	62063	51068	44492	36550	32615	31210	-1.6	-5.2	-3.3	-1.6
Diesel Hybrid	0	204	2282	14763	27781	33566	34755	36019	36866	34984	53.4	8.6	0.7	-0.3
Diesel plug-in hybrid	0	0	399	5571	9005	11071	12109	16549	17204	15539		7.1	4.1	-0.6
Gasoline Conventional	150450	149260	150501	129299	97034	82817	71886	55892	47313	44737	-1.4	-4.4	-3.9	-2.2
Gasoline Hybrid	24	221	2423	18580	37354	48897	55042	64346	65909	59817	55.8	10.2	2.8	-0.7
Gasoline plug-in hybrid	0	0	362	5958	10468	13958	16163	21366	22335	20830		8.9	4.3	-0.3
LPG	4849	8234	13012	16714	18222	22217	24633	22878	20951	20247	7.3	2.9	0.3	-1.2
CNG	718	976	2465	4989	8626	13173	15671	15933	16893	18656	17.7	10.2	1.9	1.6
E85	0	6	17	125	716	2384	4385	7328	9025	9056	35.7	34.3	11.9	2.1
Electric	0	0	2	81	1761	5380	8755	12424	13953	14464		52.2	8.7	1.5
Hydrogen	0	0	0	1	329	1034	1893	3931	5467	6725		102.1	14.3	5.5
2wheelers	**31568**	**33229**	**36238**	**38756**	**41307**	**43777**	**45474**	**46516**	**46656**	**46700**	**1.6**	**1.2**	**0.6**	**0.0**
Gasoline	31568	33229	36238	37705	39753	41608	42692	42805	40882	39614	1.3	1.0	0.3	-0.8
Electricity	0	0	0	1051	1554	2169	2782	3711	5774	7086		7.5	5.5	6.7
HDVs, buses and coaches	**8580**	**9479**	**10150**	**10629**	**10946**	**11514**	**11904**	**12104**	**12047**	**11907**	**1.2**	**0.8**	**0.5**	**-0.2**
Diesel Conventional	8565	9457	10026	10089	8318	7094	5963	5265	4952	4562	0.6	-3.5	-2.9	-1.4
Diesel Hybrid	0	6	68	421	2415	3967	5232	5856	5818	5706	54.0	25.2	4.0	-0.3
LPG	2	2	12	39	83	156	223	294	352	407	36.3	14.7	6.5	3.3
CNG	13	15	44	79	120	189	261	334	418	521	18.4	9.1	5.9	4.6
Electric	0	0	0	0	10	96	194	284	376	490		74.9	11.4	5.6
Hydrogen	0	0	0	0	0	12	32	72	132	222		121.4	19.4	11.9
Total annual cost excl. disutility (in million Euro'08)	**2421023**	**2603530**	**2807400**	**3065342**	**3307623**	**3512998**	**3689965**	**3830880**	**4057691**	**4248368**	**1.6**	**1.4**	**0.9**	**1.0**
Passenger transport	**1993288**	**2130739**	**2264852**	**2469996**	**2668219**	**2843293**	**2987584**	**3090342**	**3273124**	**3418217**	**1.5**	**1.4**	**0.8**	**1.0**
Public road transport	47158	52701	56180	60246	65400	67382	69956	71916	75497	79653	1.3	1.1	0.7	1.0
Private cars	1590465	1692455	1774381	1916665	2057219	2185468	2286455	2346147	2459863	2553715	1.3	1.3	0.7	0.9
2wheelers	46744	48916	52910	59999	67230	70067	73138	76350	80241	81698	2.1	1.6	0.9	0.7
Passenger light duty vehicles	113667	124450	135189	143878	150595	159582	166544	173107	183697	187763	1.5	1.0	0.8	0.8
Rail	74543	78191	81298	84317	88092	89860	91655	94817	101559	107756	0.8	0.6	0.5	1.3
Aviation	112942	125854	155999	195172	229337	260271	288599	316314	359431	393648	4.5	2.9	2.0	2.2
Inland navigation	7770	8172	8896	9719	10346	10664	11237	11691	12835	13985	1.7	0.9	0.9	1.8
Freight transport	**427736**	**472791**	**542548**	**595346**	**639404**	**669705**	**702381**	**740539**	**784566**	**830151**	**2.3**	**1.2**	**1.0**	**1.1**
Heavy duty vehicles	298800	338407	392831	433566	467375	489444	516653	548213	583691	620692	2.5	1.2	1.1	1.2
Freight light duty vehicles	31420	33153	34512	35573	39128	42318	45021	47675	51199	53859	0.7	1.8	1.2	1.2
Rail	55914	58699	67894	75114	78118	80408	80655	81627	82674	84695	2.5	0.7	0.2	0.4
Inland waterway navigation	41602	42531	47311	51093	54782	57535	60051	63024	67002	70905	1.9	1.2	0.9	1.2
External costs (in million Euro'08) (1)	**447714**	**404222**	**408874**	**416097**	**429672**	**441976**	**445296**	**454024**	**447010**	**433067**	**0.3**	**0.6**	**0.3**	**-0.5**
Disutility costs (in million Euro'08)	**0**	**186**	**34786**	**64298**	**144010**	**161562**	**224516**	**266749**	**424898**	**628472**	**79.4**	**9.7**	**5.1**	**8.9**
Passenger transport	0	183	16336	47691	119192	133343	188318	216191	342736	512557	74.5	10.8	5.0	9.0
Freight transport	0	4	18450	16607	24818	28219	36198	50557	82162	115914	132.3	5.4	6.0	8.7
Total costs (incl. disutility and external costs)	**2421023**	**2603716**	**2842186**	**3129639**	**3451633**	**3674560**	**3914481**	**4097629**	**4482589**	**4876840**	**1.9**	**1.6**	**1.1**	**1.8**

(1) *External costs include accidents, noise, air pollution and congestion*

Source: PRIMES-TREMOVE Transport Model