Ea Energy Analyses

CO_2 Emissions from Passenger Vehicles

Analysis prepared for the Danish Petroleum Association

Prepared by Ea Energy Analyses

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Table of Contents

1 Summary and Conclusions

Background

The transport sector's prospects of contributing to a reduction in the greenhouse gas emissions and in the dependency on fossil fuels constitute one of the central topics of the ongoing debate on climate and energy. This is an issue frequently involving comparisons between CO_2 emissions from electric cars and from more conventional car types.

In order to present an accurate picture, such comparisons should be carried out between car types that are comparable with respect to size, weight, comfort, travel range, safety, etc. They should, moreover, include emissions from the full energy cycle on the basis of a so-called well-to-wheels assessment.

Issue

For purposes of establishing an objective standard of reference, the Danish Petroleum Association has asked Ea Energy Analyses to conduct an assessment and comparison of CO_2 emissions associated with the operation of a standard car based on different engine technologies and drive systems now (2010) and in the future (2015 and 2025). The analysis includes the following drive-system configurations: petrol engine, diesel engine, hybrid, plug-in hybrid and ”pure” electric car.

With respect to petrol- and diesel-driven cars, biofuel contents of 5% in 2010, 7.5% in 2015 and 10% in 2025 have been allowed for. This analysis uses a spreadsheet-based energy-flow model taking its point of departure in the vehicle's requirements as to mechanical operation; electrical operation such as light, ventilation etc.; and heating.

Electric cars and travel ranges

In the near future, the automotive industry is expected to be capable of supplying electric cars of limited travel range (less than 150 km before recharging) and lower top speeds (approximately 130 km/h) than those applying to the other analysis configurations. In these respects, the electric car is not directly comparable to the other configurations. This analysis has therefore included a sixth configuration. This configuration – labelled ”Electric car max” – represents an electric car with a considerably larger battery and travel ranges of close on 500 km in 2010, 630 km in 2015, and over 1000 km in 2025 where it will be on a par with the petrol car. Apart from consequences such as economy and space, the larger and heavier battery will also mean an increase in the car's energy requirements. Battery-change systems for increased travel ranges have not been included in the analysis.

Definition of a ”standard car”

For purposes of making a comparison between the various car types, in spite of their significant property differences, it was necessary to introduce a definition of a ”standard car” into the analysis. This car was then equipped with the various drive-system configurations, thus facilitating a comparison between the CO_2 emissions from the different drive systems.

The definition of the standard car has been based on commonly found smaller compact medium-class cars such as Peugeot 207, Ford Focus, and VW Polo and Golf. The standard car has been structured in five different configurations differing as to the weight and properties of the drive system; brake-energy regeneration; the heating method of the car; and whether the energy required by the car is supplied by way of petrol, diesel or electricity.

The energy required by standard car to overcome rolling resistance, wind resistance and braking loss at mixed driving has been calculated to approximately 90 Wh/km for the petrol and diesel versions. An additional 15 Wh/km for lights, ventilation, etc. brings the total ”net energy requirement” to just under 105 Wh/km. The other configurations are heavier and, hence, have increased net energy requirements.

Well-to-wheels

The emissions dealt with by this analysis comprise emissions attached to the entire chain from oil well or coal mine, via refinery or power station (here referred to as ”upstream”) to emissions deriving from the actual energy consumed by the car's drive system.

Marginal energy production

The extent of emissions related to the production and consumption of petrol, diesel and electricity will very much depend upon the types of oil well and refinery in question or upon the type of power station involved in the production of the electricity. This analysis takes its point of departure in the so-called marginal energy production. Marginal production facilities are constituted by being precisely such plants that manufacture more energy in case of increasing demand, whereas other plants will not be affected by minor fluctuations in consumption. In a well-functioning market, marginal production facilities will typically have the highest operating costs.

The introduction of marginal energy production into the analysis will give the truest representation of the factual CO_2 consequences resulting from an in- or decrease in oil or electricity consumption.

With respect to oil, gas and coal, determining exactly which wells or mines are marginal can be a complex matter. As an approximation, this study presupposes the energy consumption pertaining to the extraction of coal, oil and gas from marginal sources to be 50% above the average.

As a rule, the marginal electricity production of the North European power supply system, of which Denmark is an integrated part, is based on coal and, to a lesser extent, natural gas. In Scandinavia, the CO_2 emissions relating to the marginal electricity consumption at low-tension levels has been calculated to a little less than 1000 g CO_2/kWh for 2010, inclusive of upstream loss in connection with extraction.

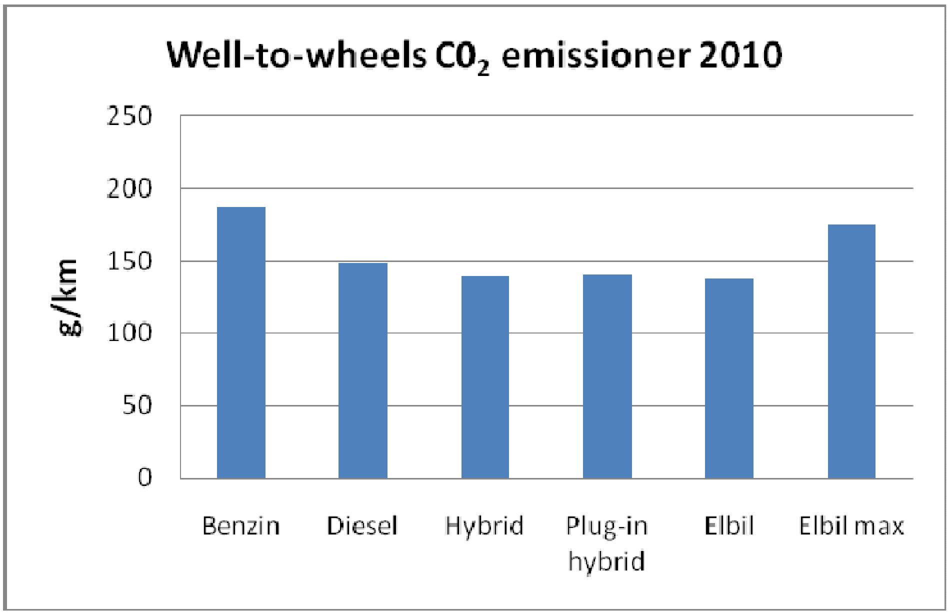

Figure 1: The 2010 CO2 emissions from six different designs of the standard car. Electric car max is similar to electric car, but with enhanced battery capacity and, hence, enhanced travel range. The figures also include ”upstream” emissions from oil wells and coal mines and from refineries and power stations. Petrol and diesel contain 5% biofuel.

Results

Figure 1 above illustrates the six configurations' total 2010 well-to-wheels CO_2 emissions per kilometre travelled.

The CO_2 emissions from the hybrid cars and the electric car are at identical levels, whereas the diesel car emissions are 8% higher. Emissions from the petrol car and the electric car max (electric car with enhanced battery capacity) are somewhat higher. This is due to the fact that the petrol car does not utilise the energy quite as efficiently as does the diesel car, and the enhanced battery capacity of the electric car max makes it slightly heavier.

Expected development towards 2025

Due to more energy-efficient engines, transmissions, etc., this analysis anticipates considerably reduced future CO_2 emissions from the various configurations. Thus, it is for instance assumed that the petrol car's efficiency can be improved by app. 30% towards 2025 and slightly less for the diesel car. The improvement potential of the electric car is especially expected as improved electric engines in combination with reduced losses in battery and charger. Moreover, with respect to the electricity-based cars, lower emissions will be a consequence of a reduction in emissions from the marginal electricity production in Scandinavia.

Figure 2 illustrates the results for 2010, 2015 and 2025. As compared with 2010, emissions from all configurations will be reduced by 30% - 40% by 2025.

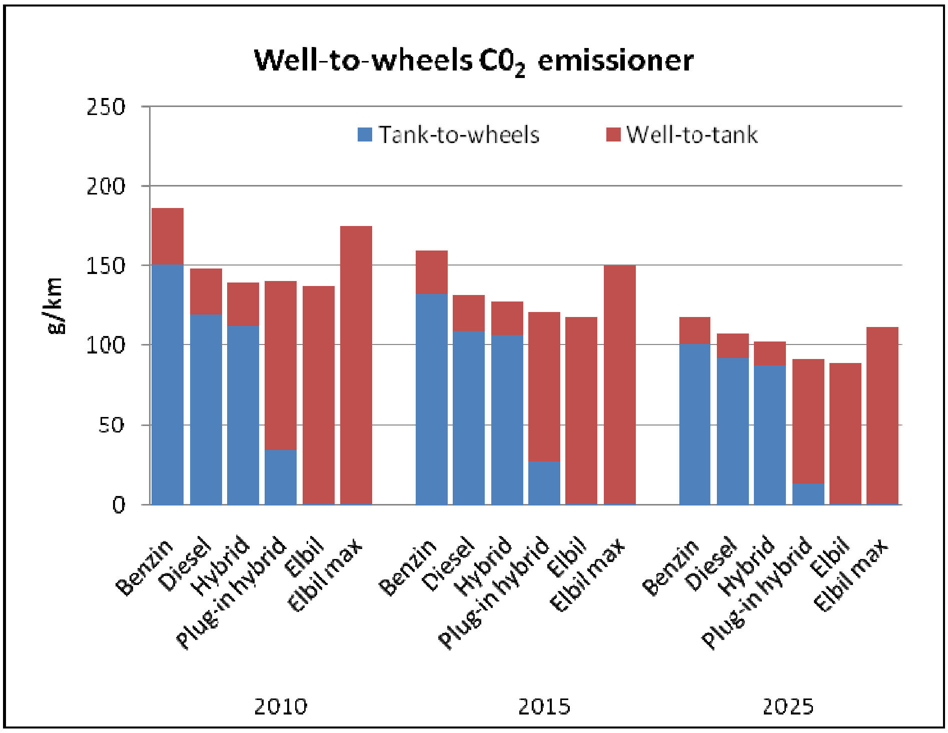

Figure 2: Development in CO_2 emissions from 6 different standard-car configurations in 2010, 2015 and 2025

Table 1: Key figures from Figure 2. Tank-to-wheels (TtW) Well-to-tank (WtT)

CO_2 emissions (g/km)									
Car type	**2010**			**2015**			**2025**		
	TtW	WtT	Total	TtW	WtT	Total	TtW	WtT	Total
Petrol	150	36	**186**	132	27	**159**	101	17	**118**
Diesel	120	29	**149**	109	22	**132**	92	16	**108**
Hybrid	113	27	**140**	106	22	**128**	87	15	**102**
Plug-in hy.	34	106	**140**	27	95	**122**	14	77	**91**
El. car	1	136	**137**	1	117	**118**	1	88	**89**
El.car max	1	174	**175**	1	149	**150**	1	111	**112**

Overall, the electric car has the lowest emissions in both 2010 and 2015, but in these years neither the total travel range nor the top speed of the electric car can compare to those of the other cars. An electric car of similar travel range would have CO_2 emissions in excess of those applicable to the diesel car and the hybrid cars.

By 2025, the electric car of the estimated configuration will have a travel range of app. 350 km presupposing improved battery technology and larger batteries. Hence, electric cars may, in 2025, be marketed as a cross between the ”electric car” and ”electric car max” configurations. On this assumption, the 2025 CO_2 emissions from an electric vehicle with a travel range of over 500 km will be fairly similar to those applicable to the hybrid car and the diesel car.

Conclusions

The analyses of this report demonstrate that, in 2010, CO_2 emission levels per kilometre travelled will be more or less the same for hybrid and electric cars, whereas the diesel car will emit 8% more and the petrol car app. 35% more. In this comparison, however, the electric car does not compare favourably to the remainder cars with respect to travel range and top speed. An electric car of the same travel range (electric car max) will be heavier; it will require more energy; and, hence, emit more CO_2 than will the diesel car and only a little less than the petrol car.

Towards 2025, a significant reduction in CO_2 emissions is anticipated, especially from the petrol car and the electric car. Such anticipations are based on a series of rather uncertain assumptions such as developments in engine technology, in battery technology and in the development of the electricity system.

A switch from petrol, diesel and hybrid cars to electric cars will cause the emissions to be transferred to the EU carbon-credit emissions trading system. The fact remains, however, that, in accordance with the EU Energy and Climate Package, any CO_2 emissions – inside as outside the quota system – exceeding the ceiling agreed upon at a European level must be compensated by a reduction elsewhere.

Inside the quota system, the above-mentioned compensation is handled by way of an already agreed trading system, whereas regulations *outside* the quota system is handled by taxation, standards, targets for renewable energy, binding agreements with the automotive industry, cost-cutting measures, etc. In the short and medium term, transference of sectors to the quota system by replacing petrol and diesel cars with e.g. electric cars will neither increase nor lower the total EU CO_2 emissions as the target agreed upon will apply until 2020.

Consequently, the main issue will be how to reach the CO_2 target most cost effectively, and not whether such reduction takes place inside or outside the quota system. This analysis, however, does not incorporate an estimate of the economic aspects. Such an assessment should include development and production costs pertaining to the vehicle itself, fuel costs, plus, with respect to electric cars, investments in and restructuring of the electricity system.

There is a long-term probability that, after 2020, electric cars and plug-in hybrid cars in combination with investments in the electricity system will become important elements in the efforts to reduce CO_2 emissions. Thus, the primary objective will be to prepare and prioritise this development for purposes of meeting the CO_2 and other prioritised societal targets without incurring unnecessarily disproportionate costs.

2 Background and Methods

The transport sectors feasibilities of contributing to a reduction in climate gasses and in the dependency on fossil fuels constitute a major topic of the climate and energy debate. In the years to come, political resolutions will be made – in Denmark and in other countries – with respect to the future economic conditions that shall be applicable to various ”car technologies”. Frequently, political debates on the transport sector's effect on CO_2 emissions tend to involve comparisons between electric cars and conventional cars.

The shortcomings can be, however, that such comparisons do not take place between car types which can be genuinely compared with respect to their size, weight, comfort, travel range, safety, etc.

The background for this project has been a desire from the commissioning party to make as transparent and objective a contribution as possible towards establishing a context for the above-mentioned political decision-making. Thus, the purpose of this analysis has been to establish a comparison between the CO2 emissions and fuel efficiency of various driveline versions of a standardised passenger vehicle, now and in the future.

The well-to-wheels method

In recent years, there has been a series of studies and analyses focused on potential technology tracks for a reduction in the transport sector's energy consumption and CO2 emissions. This includes the ”Well to Wheels” calculations carried out by the EU Commission's Joint Research Center in cooperation with EUcar and CONCAWE, latest updated in November 2008. As yet, this study does not include electric cars. Other reports, also comprising electric cars, have for instance been submitted by the Danish Energy Agency (Energistyrelsen) in 2008. Appendix 4 comprises a list of relevant studies, reports, documents and articles.

This study does not propose to introduce new knowledge on the basis of empirical studies of technologies for drive systems of passenger vehicles. The purpose is rather to analyse and evaluate existing relevant publications in order to obtain an overview of the energy consumptions and, hence, CO2 emissions, related to the most current drive-system technologies for passenger cars – comprising the potential for a reduction in CO2 emissions.

The analysis comprises emissions relating to the entire chain from oil well or coal mine, via refinery or power station, to emissions that can be ascribed to the energy consumption by the drive system of the car[1] as such.

Methods

For the purposes of this study, the total energy consumption resulting from driving a passenger vehicle one kilometre has been broken down into four elements:

1. Net energy requirement connected with the propulsion of the car
2. Energy loss connected with conversion in the car
3. Energy loss at refinery or power station
4. Energy loss at upstream production and transportation

1. The net energy requirement defines the energy required by the car to overcome rolling resistance, wind resistance and brake loss plus for functions such as lights, cooling, heating, etc.

2. Energy loss connected with conversion in the car. The net energy requirement is ”met” by the energy conversion taking place in the car's engine or, for the electric car, in the battery and a separate cabin heater. All this leads to loss of energy.

3. Energy loss at refinery or power station. The car will need energy supplied by way of petrol or diesel from a refinery, from bio fuels, or by way of electricity from a power station. Be it conversion from crude oil to petrol or diesel, from plant material to bio fuel, or from fossil fuel to electricity, plus transportation from refinery to filling station, or loss somewhere in the distribution system from power station to socket – they all lead to loss of energy.

4. Energy loss at upstream production and transportation. Finally, there is the energy loss related to the extraction of oil, gas or coal and to the transportation of the raw materials to refinery and power station.

Combined, elements 1 + 2 above may be referred to as ”tank-to-wheels”, whereas elements 3 + 4 are referred to as ”well-to-tank”.

Energy-stream model

In connection with this analysis a spreadsheet-based energy-stream model was prepared for purposes of calculating the four elements of the total energy consumption resulting from travelling one kilometre in a passenger car.

This model takes its point of departure in the standard car's *net energy requirement* calculated on the basis of the relevant drive-system configurations.

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[1] We left out CO_2 emissions occurring in connection with the manufacturing and subsequent disposal of the car as such (motor, body, batteries, etc.) which should be included in a full cradle-to-grave perspective.

The differences are represented by the drive system's weight and properties (combustion engine, hybrid or pure electricity), brake-energy recovery, plus energy required for heating the car.

Energy loss connected with conversion in the car depends on the efficiency of the drive systems with respect to converting the supplied energy (petrol, diesel, electricity) into driving activity, light, ventilation, etc. *Energy loss from refinery and power station to car* plus *energy loss at upstream production* will also be calculated.

It will then be feasible to calculate the total energy consumption for each configuration. Using various conversion factors for energy consumption to CO_2 emissions, the total CO_2 emissions can finally be calculated for each drive-system configuration.

Definition of a standard car

Today, none of the electric cars or plug-in electric cars available on the market can measure up to petrol- or diesel-car level with respect to seize, weight, comfort, safety and travel range. Since this study focuses on differences in CO_2 emissions on the basis of drive-system configurations, it was necessary to define a ”standard car”. Subsequently, this car was equipped with the various drive-system configurations comprised in the analyses.

Peugeot 207, Ford Focus and VW Polo or Golf represent examples of smaller, compact medium-class cars generally sold in Denmark. The standard car referred to in this analysis has been defined on the basis of such cars (see Table 2). Subsequent to this definition, basic data was prepared as to the efficiency of different drive systems, the weight of the cars, plus energy requirements for propulsion in accordance with the EU standards for mixed driving. Among other things, this set of basic data takes its point of departure in above-mentioned reports from the Danish Energy Agency and CONCAWE in combination with the most novel supplier information about fuel economy.

The standard car's energy requirements for overcoming rolling resistance, wind resistance and brake loss at mixed driving have been calculated to app. 90 Wh/km for the petrol and diesel versions. An additional 15 Wh/km for collateral use brings the total net energy requirement to a little less than 105 Wh/km. The other configurations are heavier and, hence, have increased net energy requirements.

The configurations chosen

Six different configurations were chosen for analysis – all playing a significant role in the debate on the transport sector's CO_2-reduction prospects towards 2025. Other technologies, such as fuel cells based on hydrogen or methanol or more ambitious applications of bio fuels than those included in the EU climate package, have not been included in this report. The reason for this is, among other things, that fuel cells cannot be expected to be marketed in a major way during the period towards 2025. Moreover, this study does not propose to establish any individual assessment of the potential contribution of biofuel to a reduction in the CO_2 emitted by the transport sector.

The configurations analysed are:

- Petrol car
- Diesel car
- Hybrid car
- Hybrid car – Plug-in
- Electric car
- Electric car max (electric car with enhanced travel range and heavier battery)

With respect to petrol and diesel-driven cars, the analysis operates with biofuel contents of 5% in 2010, 7.5% in 2015 and 10% in 2025, as specified in the EU climate-package targets.

For mixed driving, it is assumed that app. 70% of the energy requirement for propulsion will be weight-related (rolling resistance and brake loss) and that app. 30% can be related to wind resistance.[2] For cars with a capacity for brake-energy recovery, it is estimated that 15% of the energy requirement for propulsion will be recoverable (app. 40% of the brake loss). The key figures are listed in Table 2.

Table 2: Key figures (2010) for the six standard-car configurations analysed

	Petrol	**Diesel**	**Hybrid**	**Plug-in hybrid**	**El. car**	**El. car max**
Weight, kg	1117	1151	1235	1265	1209	1800
Energy requirements, road work (Wh/km)	88	91	95	97	94	125
Energy light, ventilation etc. (Wh/km)	15	15	15	17	18	18
Brake recovery (Wh/km)	No	No	No	15	14	19
Net energy requirements in total (Wh/km)	104	106	110	99	98	124
Average car efficiency	18.0%	23.0%	25.4%	53.8%	67.2%	67.2%

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[2] European Federation for Transport and Environment April 2008, Background briefing: Weight vs. footprint.

As illustrated by the table, the various cars' requirements to the energy supplied by engine and driveline (net energy requirements) differ. With a travel range of a little under 150 km, the electric car requires 98 Wh/km, whereas the heaviest car, the Electric car max, with a travel distance of about 500 km, will require a total of 124 Wh/km. However, these differences in energy requirement are relatively minor when compared with the differences existing with respect to the efficiency of the motive powers. This means that for each kilometre travelled e.g. the diesel car will require three times the energy, in the shape of diesel oil, than that required by the electric car – in the shape of electricity.

3 Framework for a Reduction in CO_2 Emissions

The most efficient measures with respect to the EU's 20% reduction target for CO_2 and with respect to reaching a target of 20% renewable energy by 2020 will be to revise and extend the EU carbon-credit emissions trading system (the EU Emission Trading System); by establishing a framework for national reductions in CO_2 outside the quota system; by enhanced application of renewable energy; and by binding targets for passenger vehicles' CO_2 emissions towards 2015. The 2020 sighting point is that new passenger vehicles will not emit more than 95 g CO_2 per km.

The expectation is that, under the auspices of the UN, a comprehensive global agreement will be entered into at the Copenhagen conference in December 2009 – in continuation of the existing Kyoto agreement which defines 2012 targets only.

Towards 2020, emissions from a wide range of major businesses representing app. 40% of the total CO_2 emissions in the EU will be regulated by means of the common CO_2 quota system. This, for instance, applies to oil and gas extraction, to refineries, and to all major electricity producing plants. Minor businesses, farms, motor traffic, plus individual households – in all representing app. 60% of emissions – will be regulated by means of national commitments.

The national commitments will be put into practice by a wide range of regulations and by legislation – national or in an EU context. The binding targets for CO_2 emissions from cars represent an example of regulation outside the quota system. Inside the quota system, app. 50% of the reduction commitment can be attained via projects outside the EU – the so-called CDM projects. The remaining sectors will be capable of attaining app. 30% of their commitment via such projects.

Collective ceiling on CO_2 emissions in the EU

Upon approval by the EU, the climate package allows the member states to transfer more sectors to the quota system. The consequence of such transfers may be an increase in the number of quotas (more quotas are issued) in order that the collective EU 20% reduction target in 2020 does not over-perform, thus increasing the total costs involved.

After 2012, the individual national reduction commitments shall follow a linear curve towards the 2020 target. Moreover, the member states will be obliged to deliver annual status reports; and, in the event that the annual targets are not reached, supplementary actions shall be taken. Other than that, the climate package carries separate binding targets for passenger vehicles – with partial targets towards 2015 and a 2020 sighting point.

Inside as outside the quota system, any emission of CO_2 exceeding the course agreed upon, must be compensated by a reduction elsewhere in the system. Inside the quota system such compensation will take place *inside* a previously agreed trading system, whereas the compensation *outside* the quota system will be implemented by means of taxation, standards, targets for renewable energy, binding agreements with the automotive industry, cost-cutting measures, etc.

Thus from an isolated viewpoint, transference of activities to the quota system by switching from e.g. petrol and diesel cars to electric cars or by other initiatives will *neither increase nor decrease the EU nations' collective* CO_2 *emissions.* The reduction commitment will simply be transferred from the nations' individual CO_2 accounts to the quota system.

4 Well-to-Wheels Emissions

Any fuel containing carbon will emit CO_2 during combustion in a car engine or in power-station furnaces. Add to this the energy consumption and CO_2 emissions released – in connection with the actual extraction of the fuel at oil well or coal mine as with manufacturing and transportation. Hence, this analysis comprises emissions related to the entire fuel cycle: from oil well or coal mina, via refinery or power station (well-to-tank), to emissions from the actual energy consumption in the drive system of the car itself.

Table 3 shows the well-to-tank emissions from petrol and diesel oil and from electricity based on coal and natural gas. Table 4 shows the total well-to-wheels emissions.

Table 3: CO_2 emissions and energy losses from consumption of 1 GJ [3] of coal-based electricity, natural-gas-based electricity, petrol, or diesel. The Scandinavian electricity market's marginal electricity is predominantly a mixture of coal-based and natural-gas-based electricity.

Well-to-tank CO_2 **Marginal perspective**	**Electricity from coal**	**Electricity from natural gas**	**Petrol**	**Diesel**
Energy to car (GJ)	1.0	1.0	1.0	1.0
Energy loss from transportation and distribution (from refinery/power st. to car)	7%	7%	2%	2%
Loss at refinery and power station	61%	50%	10%	10%
Loss ”upstream”	15%	15%	15%	15%
Total loss	**69%**	**60%**	**25%**	**25%**
CO_2 emissions from combustion (kg/GJ)	95	56	73	74
Total $C0_2$ emissions (kg/GJ)	**308**	**144**	**97**	**99**

With respect to oil, the majority of the upstream loss consists of incineration (flaring) of volatile gasses (methane etc.) plus energy for re-injection. For coal-based electricity, methane liberation constitutes an important factor – especially true for deep-seated mines.

For instance, the table illustrates that for each GJ of petrol supplied to a tank, there will be a total of 97 kg in CO_2 emissions. The marginal perspective presupposes that energy loss and CO_2 emissions from extraction will be increased by 50% as compared with the global mean value. Where the marginal crude oil is North Sea oil, the figures will be lower; and in case of oil from e.g. the Canadian tar-sand areas, the figures will be higher.

The table also shows the emission factor for coal-based electricity consumption to be 308 kg/GJ and 144 kg/GJ for electricity consumption based on natural gas.

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[3] 1 million Wh = 1000 KWh = 3.6 GJ

Table 4: Emissions per GJ energy transferred by cars via the wheels to the road. The figures have been based on the well-to-tank emission figures in Table 3.

Well-to-wheels CO_2 **Marginal perspective**	**Electr.car (coal)**	**Electr.car (natural gas)**	**Petrol car (crude)**	**Diesel car (crude)**
Well-to-tank CO_2 emissions kg/GJ	308	144	97	99
Car-efficiency total	67%	67%	18%	23%
Total CO_2 emissions kg/GJ	**458**	**214**	**541**	**429**

The table illustrates that an electric car supplied with electricity that is 100% based on natural gas will emit half as much CO_2 as a diesel car. Were the electric car to be based on 100% coal-based electricity, then the electric car would have emission figures slightly higher than the diesel car's. The subsequent analyses of this report are based on a mixture of fuels for the production of electricity; just as the diesel and petrol cars contain a small amount of biofuels that will affect the total picture.

The two tables also show that while the electric car has a considerably higher energy efficiency than the petrol and diesel cars (Table 4), then the loss associated with the power station producing the electricity is considerably higher than that connected with the refinery producing petrol and diesel oil. Overall, the electric car, however, has a considerably higher well-to-wheels efficiency.

Electricity Production in Scandinavia

The electricity applied in electric cars will not directly give rise to local emissions (except from petrol furnaces for cabin heating). Electricity being manufactured from fossil fuels will, however, generate CO_2 at the power station. Hence, the manufacturing process applicable to the electricity used in electric cars in Denmark and in Scandinavia is a central issue of this analysis.

Average electricity

Scandinavian electricity production is, in general, based on app. 50% hydro power, just under 25% nuclear power, 25% heat energy (coal, gas, oil, peat and biomass) plus app. 2% wind energy. Substantial trading takes place between the Scandinavian countries, and the pan-Scandinavian electricity market seems to be well functioning. All the countries have introduced measures to increase the quantity of sustainable energy.

The majority of the Scandinavian power generators are subject to the EU CO_2 quota scheme aiming for a 20% reduction towards 2020. The Scandinavian electricity market is linked to continental Europe by way of connections to Germany, Holland and Poland; and the trade between Scandinavia and the Continent is significant.

Marginal electricity

Hydro and wind power is, in particular, dependent upon rainfall and wind conditions with nuclear power acting as basic load. In most countries, electricity is also manufactured at natural-gas-powered plants, and in some countries even at coal-based plants. As a rule, the most expensive production units of the interlinked electricity market will usually be the ones delivering the *marginal* electricity production. In general, the interlinked electricity market's coal-based, gas-based and, to a lesser extent, oil-based plants are the most expensive. This means that in the event of a slight increase in the electricity consumption of the Scandinavian countries, then the extra electricity consumption will be supplied by a coal- or natural-gas-based plant, while the quantity of hydro, nuclear or wind power will only be affected in exceptional cases. This may happen in case of years with extreme precipitation (wet years) where the water cannot be fully exploited; or in case of so-called bottlenecks in the electricity system where the wind-power plants will have to be downgraded. Yet, the renewable-energy content of marginal electricity production, as a result of such conditions, is considered to be insignificant (less than 1%).

Model calculations using the electricity-market model Balmorel show that, based on a normal annual rainfall in 2010, the electricity for an increased Scandinavian consumption will be based on app. 80% coal and app. 20% natural gas, thus confirming existing analyses.

Renewable energy and marginal electricity in the future

Towards 2025, a considerable increase in the volume of renewable energy may be expected due to, for instance, EU´s climate package; and technologies for accumulation and storage of CO_2 (CCS) are likely to be developed and implemented to a limited extent. Biomass-based sustainable energy may, in certain circumstances become marginal, whereas coal-based plants with CCS will probably be operated as basic-load plants in line with nuclear power plants. On the face of it, this means that the CO_2 content of the marginal electricity production will only be affected to lesser extents, since the change in fuel between coal and biomass will only occur to a limited extent.

On the other hand, it seems likely that, towards 2025, there will be a certain *decisional* correlation between enhanced electricity consumption and a desire for an increased part of the electricity consumption being based on renewable energy or CCS technologies. Thus, an enhanced electricity consumption will probably contribute to investments being made in renewable energy or CCS. This correlation is, among other things, owing to the electricity consumption's direct influence on the trading price of CO_2 emission quota. On this background, it may be argued that the long-term marginal electricity production will comprise increased quantities of renewable energy. It is, however, uncertain to which extents such direct correlations will, in practice, be visible before 2015 and 2025.

Yet, the EU climate package and national actions will unquestionably give rise to an *average* electricity consumption containing increased volumes of renewable energy. Since EU's collective renewable-energy target is 20% of the energy consumption, the renewable energy included in the energy consumption of electric cars will to a certain extent displace the expansion of renewable energy elsewhere – for instance in connection with household heating.

A possible consequence of flexible electricity consumption, of which electric cars could perhaps become a good example, might facilitate the incorporation of larger amounts of wind power in the electricity system. In this connection, , the electric car's efficiency, seen in relation to the number of other technological and regulatory feasibilities for increasing the amounts of wind power, has yet to be subjected to substantial examination, however. In case decisions to substitute a portion of the transport sector with electric cars are tied to decisions about increasing the expansion of wind power, then the marginal electricity consumed by electric cars will, in the longer term, to an increasing extent come to be represented by renewable energy.

On the background of the above estimates, this report assumes that, by 2015, for instance 5% of the marginal electricity production (the electricity production supplied to electric vehicles) will be based on renewable energy – against 0% in 2010. The estimated figure for 2025 is 15%. However, the 2025 figure is subject to considerable uncertainty, since it rests on political and commercial decisions that have yet to be taken. Also, it is not clear how the renewable energy attributed to the transport sector will affect the countries' goals for other sectors.

5 A Review of the Drivelines of Vehicles in 2010, and towards 2025

This section is a brief introduction to the five different drivelines dealt with in this report. This also includes the efficiency improvements to be expected – in the short-term, and towards 2025.

Petrol cars (the Otto engine)

Briefly stated, the petrol- and diesel-car motive driveline consists of an engine, a gear box, and power transmission to the wheels. As a rule, the power transmission in modern cars takes place to the car's front wheels resulting in improved road grip but slightly increased energy loss.

The figure overleaf has been retrieved from the website of the U.S. Department of Energy (DOE) and illustrates the ratios of energy loss associated with a passenger car with a petrol engine (Otto engine) at mixed driving. According to the figure, only app. 15% of the energy supplied is utilised as net energy for propulsion of the car plus energy for equipment such as air-conditioning system, light, boost fan, etc. The remainder energy is released in the process as heat loss. The majority of the loss takes place in the engine itself – for tractive efforts, but losses during idling and by transmission of power in gearbox and wheels are also of significance.

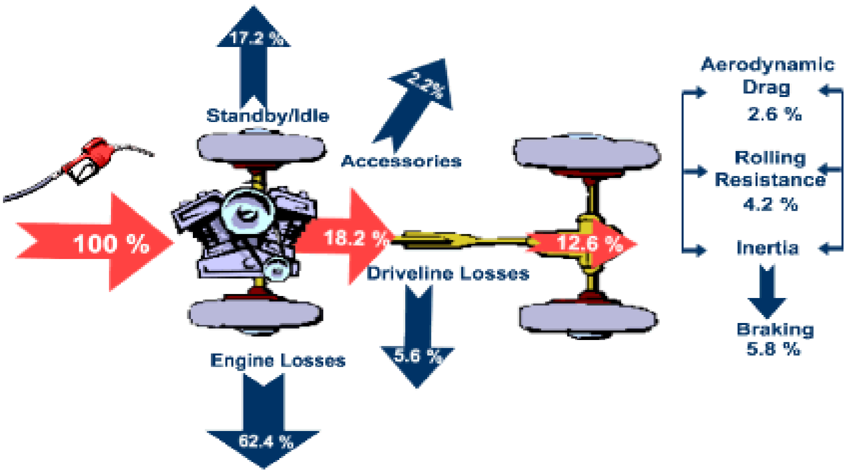

Figure 3: Illustration of energy losses in a petrol-driven passenger car, USA. The figure shows that, in total, only 12.6% of the energy content goes to a net energy consumption (wind resistance, rolling resistance and braking energy). Source: www.fueleconomy.gov

Today, the Peugeot 207 is available in a 4-cylinder version with a 95 horsepower engine (70kW). Likewise, the Volkswagen Golf can be delivered in a 4-cylinder, 80-horsepower version (59 kW). These and similar models from other car manufacturers have been selected to constitute the basis for the theoretical standard car of this study.

In the appendices to the 2008 report “Teknologivurdering af alternative drivmidler til transportsektoren” (A Technological Assessment of Alternative Fuels for the Transport Sector), the total efficiency for the petrol-driven engine was assessed to app. 16% at mixed driving. The report is, however, based on 2005 and 2006 data. The report anticipates an increase in efficiency to 23.5% by 2025. These figures also comprise losses in gears and power transmission.

The future

With respect to conventional petrol engines a series of improvement potentials are expected to result in considerably higher efficiencies over the next 15 years. Potentials realised by way of new materials and advanced engine operation. For instance direct fuel injection (DISI) is expected to be standard in a matter of a few years. As can be seen in figure 3, idling loss constitutes a relatively significant source to losses. Various ‘Start Stop’ technologies are being developed. Here, for purposes of saving fuel, the power control will entirely cut off the engine in certain situations.

On the basis of the COWI report and other references, this study has selected efficiencies of 18.0% in 2010; 20.0% in 2015; and 23.5% in 2025.

Diesel cars

The diesel engine works without spark plugs and typically at considerably higher compression ratios and combustion temperatures than the Otto engine. This facilitates a higher efficiency potential. Previously, the diesel engine was, however, characterised by being heavier and having lower accelerating capacities, but there has been a considerable development in these respects.

Both the Peugeot 207 and the Volkswagen Golf are available in diesel versions with direct fuel injection and turbo charger. Hence, these cars can serve as the basis for the diesel version of our standard car. On the basis of 2006 data, the COWI report referred to above assess the efficiency of the diesel engine to be 21%, increasing to 25% in 2025. These figures are inclusive of other driveline losses.

The future

The diesel engine's improvement potential is not estimated to be as high as that of the petrol engine because, among other things, the departure levels are higher and because much research has already been implemented. The expectations are, in particular, focussed on start-stop technology, on improved control, and on a further reduction in weight.

On the basis of previous studies and more recent data, this study has chosen to work with efficiencies of 23.0% in 2010, 24.5% in 2015, and 26.0% in 2025.

Hybrid cars

As the name ”hybrid” suggests, this vehicle is a combination – a hybrid – between the drivelines of two types of car, namely between the combustion-engine-based and the electric car. Thus, the hybrid car will have two power sources and, hence, a fuel tank as well as battery storage. One advantage of the hybrid car is that the combustion engine will, to a larger extent, be capable of running at stable revolutions and thereby be closer to its ”peak point” of high efficiency. Another advantage is a considerable reduction in engine size, as the electric engine will contribute the necessary torque during acceleration – especially at low revolutions. A third advantage is the potential for accumulating and reusing part of the brake energy via the car's electric engine and battery.

Hybrid cars come in several models, and they can, in practice, be classified into two main classes: parallel and serial hybrid. In the parallel hybrid car, both the combustion engine and the electric engine have direct power transfer to the wheels, whereas, in the serial hybrid car, it is the electric engine that propels the car forward. Here, the combustion engine runs a generator for charging the battery. The parallel hybrid requires improved control and will typically have a larger petrol engine and a smaller battery. On the other hand, it avoids a part of the loss in generator and battery characterising the serial hybrid car.

To date, the majority of hybrid cars sold have been parallel hybrids. Some are mainly fuel driven while others have larger batteries and focus on electricity operation.

Being an example of a so-called full parallel hybrid, the Toyota Prius has been selected as the technology representing the theoretical hybrid version of our standard car.

This study operates on the assumption that the petrol engine of the hybrid car has an efficiency of 22%, that the electric engine has an efficiency of 83%, and that the battery dis- and recharging efficiency will be 75%. It is further assumed that app. 90% of the work will be carried out by the petrol engine and 10% by the electric engine. The total efficiency has been calculated to 25.4%.

The future

The hybrid-car technology is a relatively new one with room for improvement, especially through control technology and, on the electricity side, in the shape of lowered engine and battery losses. The combustion engine will also become more efficient, but since the hybrid car already exploits this potential by running at fixed revolutions, the potential here is expected to be somewhat lower than is the case for cars run solely by petrol or diesel engines..

This study operates on the assumption that the total efficiency will increase from 25.4% in 2010 to 26.5% in 2015 and 28.8% in 2025. The anticipated increase is also founded on the assumption that the electric engine's part of the total work will be increasing.

Plug-in Hybrid

Similar to the “conventional“ hybrid cars, plug-in hybrid cars are also manufactured as either serial or parallel versions. The plug-in cars are distinguished by their capacity for charging the battery both onboard the car via the combustion engine or via plugging into the mains electricity. Typically the plug-in cars will have a somewhat larger battery than other hybrid cars, and this study assumes that these cars will primarily be sold as serial hybrids. The plug-in cars are, by some, defined as being a natural stepping stone in the development towards actual electric cars.

This study operates on the assumption that the total efficiency will increase from 53.8% in 2010 to 66.6% in 2015 and 74.8% in 2025. This increase is equally due to the expectation that the electric engine's part of the total work will be increasing.

The electric car

Since the aftermath of the oil crises of the early 1980'es, there have been many attempts all over the world to develop electric cars capable of reaching a mass market. Not until the commitment of the French car industry (PSA) in the 1990'es did we see electric cars resembling, in size, roadability and personal safety, the cars that consumers were used to. Nonetheless, the electric car did not succeed this time either – first and foremost for reasons of battery technology.

Today, a wide variety of electric cars are manufactured and sold all over the world – the majority being small vehicles not meeting this report's standard-car requirements. The Think, Kewet and Reva represent examples of electric cars currently available on the Danish market. Other versions – such as reconstructed Fiat models from Elbil Danmark or reconstructed Nissan models from Afuture EV – are expected to be introduced on the Danish market in the course of 2009.

The driveline of the electric car consists of a charger, batteries plus one or more electric engines. Even though the last 20 years has seen a considerable development within battery technology, the weight and volume of the battery – and hence the car's travel range and spaciousness – still represent a considerable challenge. Moreover, the heavy battery will increase the energy consumption of the car. While modern lithium batteries have a capacity for storing app. 80- 20 Wh energy per kilo, the energy content of petrol and diesel is more than 100 times higher. However, the electric engine is not as heavy as the petrol and diesel engines, and its capacity for exploiting the stored energy is much more efficient. Due to its significant impact on the car's weight, much research into electric cars is focused on a reduction in onboard energy losses.

The most recent electric engines have a high efficiency over large load areas; and, also, their lithium batteries and advanced control technologies contribute to a significant reduction in the electric losses connected with re- and discharging.

This study assumes a total engine efficiency of 83% and a re- and discharging efficiency of 90%. Combined with the loss in the charger itself, the total efficiency of the electric car will be 67.2% in 2010 which is equivalent to the figures stated by e.g. Mitsubishi for their i-MiEV expected to be sold in Denmark towards the end of 2010.

The future

Since driveline losses are already relatively low, the potential for improvement of the electric car is limited. Today, American Tesla Motors already states efficiencyes for their Roadster to be higher than those described above. This is a customised and relatively expensive car. This study expects the efficiency of the electric car to increase to 71.4% in 2015 and 80.4% in 2025.

It should be noted that, due to expected progress within battery technology (the performance/weight ratio), we have calculated the electric-car's battery capacity to increase from 22 kWh in 2010 to 28 kWh in 2015, and 40 kWh in 2025.

6 Results

Figure 4 illustrates the total well-to-wheels energy consumption required by a standard car to travel one kilometre in 2010. In this figure, the fundamental energy requirement necessary to overcome drag resistance, rolling resistance, brake loss, plus energy for headlamps and other equipment of the car has been labelled ”net energy requirement”. The point of departure of this analysis is the assumption that, with the exception of variations arising from differences in the weight of the cars, different feasibilities for exploiting some of the brake energy and different cabin-heating systems, the requirements to net energy will be identical in all configurations.

With a little over 350 kJ/km (98 Wh/km), the electric car has the lowest net - energy requirement. In spite of the higher weight, the consumption is lower, since a considerable quantity of the brake energy can be reused. The electric car max has the highest net energy requirement because of its enhanced battery weight for purposes of attaining travel ranges approaching those of the other cars.

In order to meet this energy requirement, the car's engine needs to convert fuel and electricity into mechanical work, into light, and into heat. The figure illustrates how the losses in connection with this conversion in the car differ considerably in the various configurations. The drive system based on electric engine and battery has the highest efficiency, whereas the drive system based on a petrol engine and a gearbox has the lowest efficiency. These calculations assume that 90% of the hybrid-car work will take place directly via the combustion engine and that 10% will pass through charger, electric engine and battery. With respect to the plug-in hybrid car, 30% of the work is assumed to be delivered by the petrol engine and 70% by the electricity mains system.

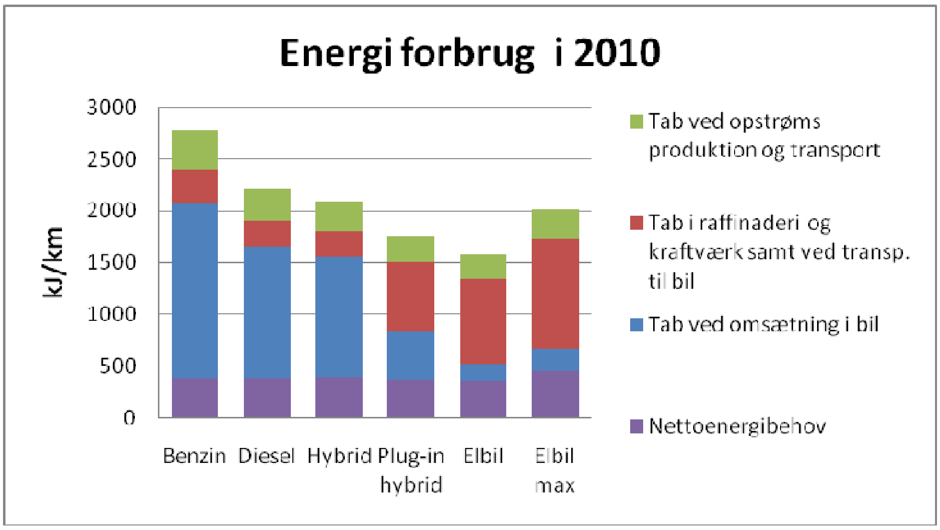

Figure 4: Well-to-wheels 2010 energy consumption for the 6 different configurations of the standard car.

Before the fuel and electricity reaches the car, there will be an energy loss along the way. With respect to electricity, the loss at the power station is quite significant. This report assumes efficiencies at the marginal coal-based power stations of 39% and 50% for power stations based on natural gas. With respect to the fuel-based driveline, there is only a 10% loss by refinement of the crude oil at the refinery. For biofuels, constituting 5% of the fuel, a loss of 50% is anticipated for the marginal first-generation plants.

Finally, there is an energy loss in connection with the researching and recovery of fossil fuels. This report assumes that 15% of the marginally recovered energy will be lost. These figures are subject to some uncertainty. Add to this a minor loss in connection with transportation to refinery and to power station.

Figure 5 overleaf illustrates the equivalent figures for 2025 (the energy consumption for 2015 lies between 2010 and 2025, and the data can be found in appendix 2). The figure mirrors the expectations to the continued development of the combustion engine – in particular the petrol engine. Where the petrol car has a fuel economy of 18.5 km/litre in 2010, this will have been increased to 26.2 km/litre in 2025. The corresponding figures for the diesel car will be 25.3 km/litre and 30.9 km/litre, respectively. The fuel economy for the electric car cannot be directly expressed as km/litre; however the electricity-based drivelines will also display a substantial increase in efficiency – from app. 67.2% to a little more than 80.4%. The improvement is especially ascribable to decreased losses in batteries, charger and in the engine itself.

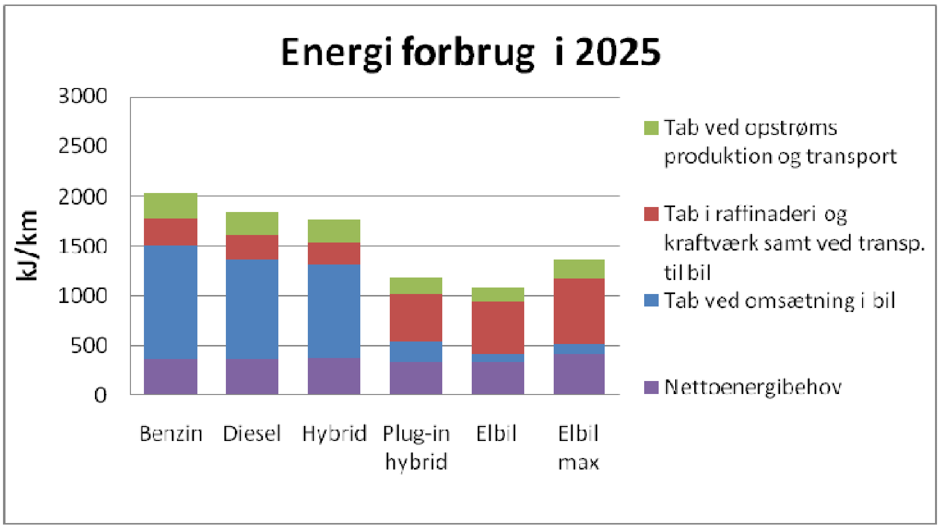

Figure 5: Well-to-wheels 2025 energy consumption for the 6 different configurations of the standard car.

The 2025 upstream energy efficiency figures have been calculated as being identical to the 2010 figures. One exception is found in the electricity system, where it is assumed that the marginal coal- and natural-gas-based power stations will be improved by 5% as a result of the oldest North European power plants being scrapped, whereby younger-generation plants will become marginal. Add to this that, by 2025, 15% of the marginal electricity production is anticipated to be based on renewable energy. These calculations are subject to some uncertainty, but may be assumed to lie somewhere between 10%-20%.

From energy consumption to CO_2 emissions

Figure 6 shows the total 2010 well-to-wheels emission of CO_2 in grams per kilometre. The CO_2 emissions have been calculated on the basis of the energy consumptions shown in Figure 4. The marginal Scandinavian electricity production for 2010 has been calculated to being based on 20% natural gas and 80% coal. In practice, a smaller quantum of what has been entered as coal in the calculations will probably be Finnish peat and German or Polish brown coal. This will not, however, influence the total picture.

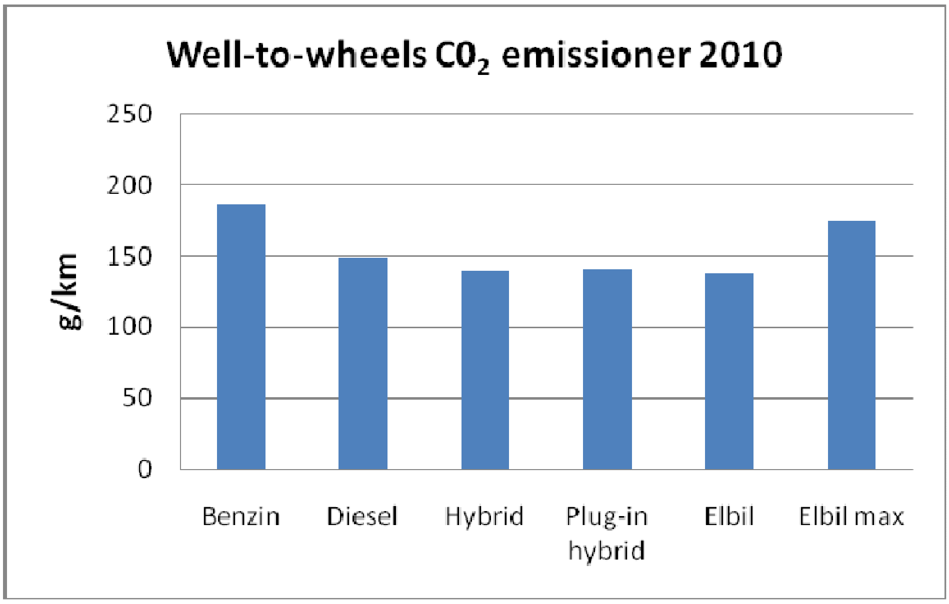

Figure 6: The 2010 CO_2 emissions from the standard car in six different configurations. The electric car max is identical to the electric car except for its travel range of app. 500 km.

The figure shows the petrol car and the electric car max as having the highest CO_2 emissions, whereas the electric car and the hybrid cars display comparable emission figures. In this connection it should be stressed that the electric car of these calculations has yet to be marketed and, also, that it has a considerably lower travel range and top speed than the other configurations.

Figure 7 illustrates the expected development in CO_2 emissions from 2010, via 2015 to 2025. By 2025 there will, for all configurations, be a reduction in emissions by 30%-40% as compared with 2010. The most significant development is expected in connection with the petrol car, especially due to improvements of engine and driveline as such. As mentioned above, improved efficiencies are also expected for the electric car. Add to this that, by 2025, part of the electricity production is expected to be based on renewable energy.

Collectively, the electric car will have the lowest emission figures in both 2010 and 2015, but the use properties of the electric car are not on a par with those of the other cars. An electric car of the same travel range as the other cars (i.e. electric car max) will require a larger battery and thereby be considerably heavier. The emission figures related to electric car max will exceed those pertaining to both the diesel car and the hybrid cars.

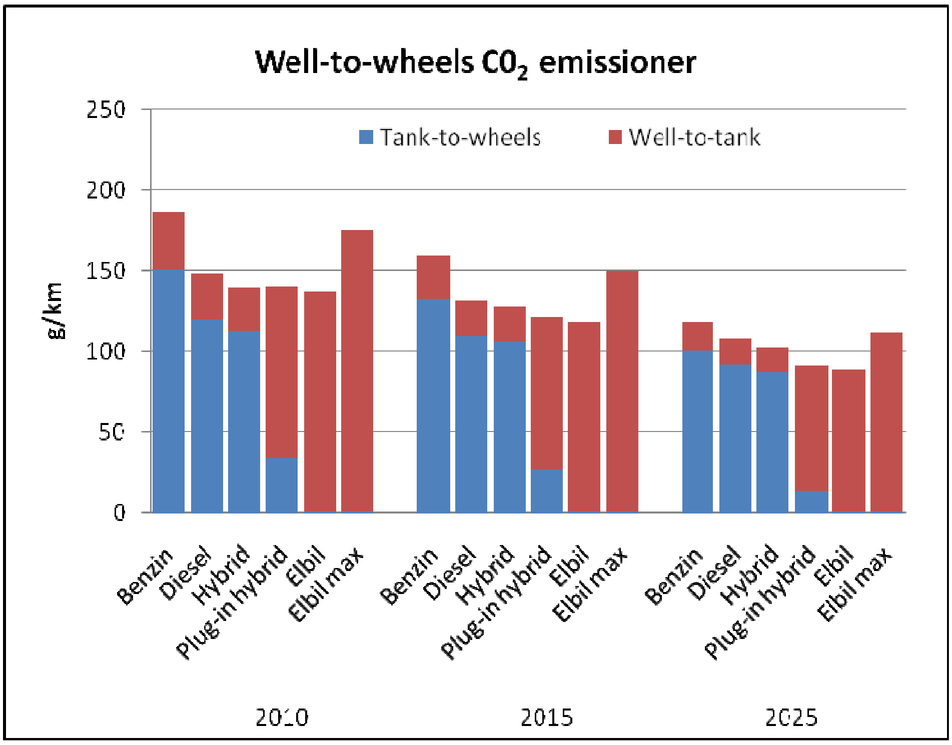

Figure 7: The development in CO_2 emissions in 2010, 2015 and 2025 in the six different configurations of the standard car. The electric car max is identical to the electric car except for its travel range of app. 500 km. in 2010.

In 2025, the electric car will still have the lowest emission figures, especially because, by now, a major part of the marginal electricity production will be based on renewable energy. By 2025 the electric car of the calculated configuration will have a travel range of 350 km. This is based on the anticipated continued development in battery technology, in particular with respect to the energy-weight ratio. This improved technology will be exploited to increase the energy-content element of the electric-car configuration. By 2025, electric cars may be marketed as a cross between the configurations shown for electric car and electric car max. On this hypothesis, an electric car with a travel range of over 500 km will, in 2025, have emission figures identical to a diesel car, albeit higher than those pertaining to the plug-in hybrid car.

Appendix 1: The Standard Car's Properties and Energy Requirements

VW Polo BlueMotion

Peugeot 207

VW Golf BlueMotion

Toyota Prius

Chevy Volt

For purposes of facilitating a comparison between the five different drive systems on a uniform basis, it was necessary to establish a theoretical “standard car“, albeit on the basis of known car models. Thus, properties such as roadability, spaciousness, carrying capacity, personal safety and comfort pertaining to the cars are assumed to be independent of the car's propulsion technology. Obviously, this is not quite true – especially seen in the light of the lower travel ranges and top speeds of those versions of the electric car currently on the market or expected to be market in the years to come.

Taking the European standard for mixed driving (NEDC) as our point of departure, we defined the amount of energy required by this standard car for overcoming energy losses from wind resistance, rolling resistance between tire and road, plus break losses. Such losses will depend on car size, shape and weight and also on driving pattern. The industry does not directly state the net energy requirement. But, on the basis of the studies reviewed, this report has assessed this to be app. 90 Wh/km.

Table 5 shows examples of smaller, compact medium-class cars which constituted the basis for the establishment of the standard car. The Peugeot 207 and the Volkswagen Golf are examples of other petrol- and diesel-driven vehicles of similar properties. The models were chosen because of their relative popularity in the Danish (and Norwegian) fleet of cars.

As mentioned above, the electric car's travel range on one charge does not measure up to the other cars' 600-900 kilometres on a full tank. Whether this will constitute a major problem to the individual car owner has not been considered since the purpose here has been that of establishing a standardised basis for comparison.
Choice of battery type will be a question of balancing various factors such as price, efficiency, life span, effect, and energy density. Modern battery systems for electric cars operate with energy densities of app. 100-120 Wh/kg. Thus the electric version of the standard car will, at mixed driving, be capable of enhancing its travel range by app. 1 km for each extra kilo added to the basic battery. The car's net energy consumption per kilometre will increase concurrently with added battery weight; and thus the utility value from the last kilos will decrease.

Hence, an electric car with a travel range of app. 650 km will weigh a little over 500 kilo more than the 2010 standard car. Even though this is not a likely configuration, an electric car with full travel range has been incorporated in line with the other car versions of the analysis.

Table 5: 2010 car models and their properties. The models have been chosen as a basis for the theoretical standard car comprised by the analysis of this report. * Estimated

Car model	Type	Fuel econ. (km/l)	CO$_2$ (g/l)	Weight (kg)	Trav.dist. (km)*	Top sp. (km/h)
VW Polo 1.2 - 70 h.p.	Petrol	18.2	128	1117	750	165
Peugeot 207 1.4- 95 h.p.	Petrol	16.4	140	1150	700	185
VW Golf VI 1.4 - 80 h.p.	Petrol	15.6	149	1302	660	172
Peugeot 207 1.4 Hdi – 70 h.p.	Diesel	22.7	117	1177	945	166
VW Polo TDI 1.6 - 75hk	Diesel	23.8	109	1207	955	170
VW Polo Blue-Motion 1.4 TDI	Diesel	26.3	99	1084	975	176
VW Polo Blue Motion 1.2 TDI	Diesel	30.3	87	1054	1100	170*
Toyota Prius	F-Hybrid	23.3	105	1383	887	170
Chevy Volt	Plug-hy	N/A	N/A	1596	710	160
Mitsubishi iMiEV	Electr.car	N/A	N/A	1080	144	130
AFUTURE EV PRO1	Electr.car	N/A	N/A	1400	250	130

Mitsubishi iMiEV

AFUTURE EV PRO1

Appendix 2: Tables and Key Figures

Key figures 2010		**Petrol**	**Diesel**	**Hybrid**	**Plug-in hybrid**	**El. car**	**El. car max**
Total car efficiency **	pct.	18.0 %	23.0 %	25.4 %	53.8 %	67.2 %	67.2 %
Fuel economy, Tank-to-wheels	km/l and km/kWh	15.8 km/l	21.7 km/l	21.1 km/l	69.2 km/l	7.1* km/kWh	5.6* km/kWh
Fuel economy, Tank-to-wheels without light, ventilation etc.	km/l and km/kWh	18.5 km/l	25.3 km/l	24.4 km/l	83.4 km/l	8.4* km/kWh	6.3* km/kWh
CO_2 well-to-wheels	g/km	186	149	140	141	137	175
CO_2 well-to-wheels except up-stream emissions	g/km	162	129	122	122	120	152
CO_2 tank-to-wheels	g/km	150	120	113	34	1	1
CO_2 tank-to-wheels without light, ventilation etc.	g/km	129	103	98	30	0	0
CO_2 saving from biofuels	g/km	1.3	2.5	1.0	0.3	0.0	0.0
Travel range	km	770	1074	923	734	156	477

* The figure does not comprise energy consumption for cabin heater

** Inclusive of loss generated by the battery and by the charger itself

Key figures 2015		**Petrol**	**Diesel**	**Hybrid**	**Plug-in hybrid**	**El. car**	**El. car max**
Total car efficiency **	pct.	20.0 %	24.5 %	26.5 %	66.6 %	71.4 %	71.4 %
Fuel economy, Tank-to-wheels	km/l and km/kWh	17.9 km/l	23.6 km/l	22.4 km/l	88.1 km/l	7.7* km/kWh	6.1* km/kWh
Fuel economy, Tank-to-wheels without light, ventilation etc.	km/l and km/kWh	21.0 km/l	27.6 km/l	26.0 km/l	107.4 km/l	9.2* km/kWh	6.9* km/kWh
CO_2 well-to-wheels	g/km	169	132	128	122	118	150
CO_2 well-to-wheels except up-stream emissions	g/km	139	115	111	106	103	130
CO_2 tank-to-wheels	g/km	132	109	106	27	1	1
CO_2 tank-to-wheels without light, ventilation etc.	g/km	113	93	91	23	0	0
CO_2 saving from biofuels	g/km	1.7	3.4	1.3	0.3	0.0	0.0
Travel range	km	860	1163	966	766	216	635

* The figure does not comprise energy consumption for cabin heater

** Inclusive of loss generated by the battery and by the charger itself

Key figures 2025		**Petrol**	**Diesel**	**Hybrid**	**Plug-in hybrid**	**El. car**	**El. car max**
Total car efficiency **	pct.	23.5 %	26.0 %	28.8 %	74.8 %	80.4 %	80.4 %
Fuel economy, Tank-to-wheels	km/l and km/kWh	21.8 km/l	26.2 km/l	25.2 km/l	161.9 km/l	9.0* km/kWh	7.2* km/kWh
Fuel economy, Tank-to-wheels without light, ventilation etc.	km/l and km/kWh	25.7 km/l	30.9 km/l	29.4 km/l	204.6 km/l	10.9* km/kWh	8.3* km/kWh
CO_2 well-to-wheels	g/km	118	108	102	91	90	112
CO_2 well-to-wheels except up-stream emissions	g/km	103	94	89	79	77	97
CO_2 tank-to-wheels	g/km	101	92	87	14	1	1
CO_2 tank-to-wheels without light, ventilation etc.	g/km	86	78	75	11	0	0
CO_2 saving from biofuels	g/km	9.6	9.6	8.3	1.3	0.1	0.1
Travel range	km	1031	1285	1074	834	362	1024

* The figure does not comprise energy consumption for cabin heater

** Inclusive of loss generated by the battery and by the charger itself

Appendix 3: CO_2 Emissions from Biofuels

The EU has issued a resolution on the admixture of 5.75% biofuels in 2010 and 10% in 2020. Since plants absorb the same amount of CO_2 during growth as they emit through combustion, the CO_2 emissions from biofuel combustion are set at nil. On the other hand, CO_2 will be emitted from cultivation and fertilisation of the fields and from the manufacturing process of the biofuel.

The directive on renewable energy issued in April 2009 in connection with the climate package comprises a schedule listing standard figures for the CO_2 emissions from biofuels. It was decided to apply these figures as expressions of the marginal production of biofuels, thus disregarding the fact that, in practice, a substantial quantity of biofuels may stem from Brazil where other emission factors may be applicable as mean values.

This study operates with first-generation biofuel technology in 2010 and 2015 based on wheat and rape for extraction of ethanol and diesel, respectively. With respect to 2025, we incorporated a second-generation technology based on straw and wood, respectively.

Table 6: Reduction in the CO_2 emissions by biofuel applications calculated on the basis of standard values from the renewable-energy directive.

CO_2 emission	**Ethanol**	**Biodiesel**
2010, 2015 – Reduction	16.0 %	38.0 %
2010, 2015 – Reduction (kg/GJ)	11.7	28.1
2025 – Reduction	85.0 %	93.0 %
2025 – Reduction (kg/GJ)	62.1	68.8

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