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SECRETARÍA DE MEDIO AMBIENTE Y RECURSOS NATURALES

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Mitigación del cambio climático

Coordinación General de Mitigación del Cambio Climático

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TECHNOLOGY CATALOGUE FOR LOW CARBON TRANSPORT TECHNOLOGIES

No. de contrato: cooperación danesa

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Bajo el Contrato (De la cooperación danesa)

Contents

Abbreviations

AMIA	Asociación Mexicana de la Industria Automotriz
ANPACT	Asociación Nacional de Productores de Autobuses, Camiones y Tractocamiones
ATEX	EU Directive 94/9/EC (Appareils destinés à être utilisés en ATmosphères EXplosibles)
BC	Black Carbon
BEV	Battery Electric Vehicle
CAPEX	Capital Expenditure
CCMEP	Mexican Danish Cooperation on Climate Change Mitigation and Energy
C&I	Control and Instrumentation
CH4	Methane
CNG	Compressed Natural Gas
CO	Carbon Oxide
CO_2	Carbon dioxide
CSP	Concentrated Solar Power
EGR	Exhaust Gas Recirculation
ESIA	Environmental and Social Impact Assessment
EU	European Union
GDP	Gross Domestic Product
GEM	Greenhouse Emissions Model
GFEI	Global Fuel Economy Initiative
GHG	Green House Gasses, e.g. CO_2 and CH4
GJ	Giga Joule
GVW	Gross Vehicular Weight
HCCI	Homogeneous Charge Compression Ignition
HDV	Heavy Duty Vehicles (vehicles with GVW higher than 3,857 Kg)
IEA	International Energy Agency
INECC	Instituto Nacional de Ecología y Cambio Climático
Kg	Kilogram
LDV	Light Duty Vehicles (passenger cars and small vans with GVW lower than 3,875 Kg)
LPG	Liquefied Petroleum Gas
MJ	Mega Joule
Mt	Metric tons
MW	Megawatt
MWh	Megawatt hour

NEDC	New European Driving Cycle
NO_X	Nitrogen Oxides
OECD	Organization for Economic Co-operation and Development
OICA	International Organization of Motor Vehicle Manufacturers
O&M	Operations and Maintenance
OPEX	Operating expenses
PHEV	Plugin Hybrid Electric Vehicle
R&D	Research and Development
SLCP	Short-lived climate pollutants
S	Sulphur
SO_2	Sulphur dioxide

1. Introduction to the technology catalogue

General introduction

The transport sector is the largest emitter of GHG and SLCP in Mexico. In 2013, the total emissions of the sector reached 191 MtCO2e, comprised of 166 MtCO2e of GHG and 25 MtCO2e of black carbon (BC) from motor vehicles, railways, ships and aircraft (INECC, 2015). According to INECC (2015), oil derived products represent 99% of the energy consumption of this sector and it represents 44% of the total energy consumption of the country. Of the total energy consumption of the sector, 92% corresponds to on road motor vehicles. Road transport includes emissions from diesel and gasoline motor vehicles and accounts for 176 MtCO2e, equivalent to 22% of total emissions of the country (INECC, 2015). There are a number of possibilities available now and in the future able to reduce the emissions. Technologies are constantly developed to become cleaner and engines to become more energy efficient. Moreover, alternative transport fuels are being developed and will be able to further contribute to the reduction in emission effects.

In addition to the technological solutions, the behavior of people is additionally important to include in the pursuit for reducing emissions. This technology catalogue, however, does not address this latter behavioral element, but considers the technological options in the transport sector that can contribute to reductions of the emissions.

The INECC under the Mexican Danish Cooperation on Climate Change Mitigation and Energy (CCMEP) presents this catalogue as a tool for planners, interest organizations, authorities and investors in the transport sector to facilitate analyzes of development in the environment and climate impacts of the transport sector.

The catalogue present the current situation for the transport sector in Mexico and for the low carbon transport technologies available in the world market and outlines future possibilities and technologies that can be introduced to the Mexican transport market to provide a basis for using the different inputs presented in this catalogue.

Background

In COP21, in Copenhagen, collaboration between Denmark and Mexico was initiated with the Mexican Danish Cooperation on Climate Change Mitigation and Energy (CCMEP). The aim of CCMEP was to support Mexico in their ambitious target of reducing 22 % of GHG and 51 % of Black Carbon in 2030 compared to 2013.[1]

[1] http://www.gob.mx/cms/uploads/attachment/file/162973/2015_indc_ing.pdf

This technology catalogue is developed as a method of ensuring that key technical and emission parameters for transport used by different stakeholders are consistent, and thereby contribute to timely adaption of new low carbon technologies.

The catalogue presents a range of different transport technologies available in the world market today and outlines future possibilities and technologies that can be introduced to the Mexican transport market.

The information presented in the transport catalogue and the complementary data and fact sheets are derived from national and international sources and has been discussed and validated with a large group of Mexican stakeholders. The data provides the best estimates of the effects.

Scope

The purpose of this catalogue is to support the strategic planning of reducing GHG and Black Carbon emissions and local air emissions in 2030 in Mexico. The catalogue equips project developers, transport planners and authorities in Mexico with a standardized approach and methodology for analyzing different technological solutions. The catalogue aims at presenting the different technologies with their potentials and barriers. Moreover, it presents the expected development in the technologies in the coming years.

To support the assessment of the different possibilities, the catalogue characterizes the most common technologies, which either are in the market today or are expected to be presented more widely in the market in future years.

Development in transport energy and emissions

According to the International Energy Agency (IEA, 2017) vehicle efficiency improvements constitute the single most important factor for reducing the carbon footprint of the transport sector in the future. Efficiency improvements are necessary to compensate for the growing number of vehicles on the road. It is foreseen by the IEA that the total number of LDV's on the road globally will double between 2015 and 2050. This can be seen from Figure 1-1 below. The figure also predicts that the vast majority of LDV's on the road in 2050 will be based on high-efficiency drivelines such as fuels cell, electric and hybrids. Only a minority will be based on conventional gasoline-, diesel- or gas-engines.

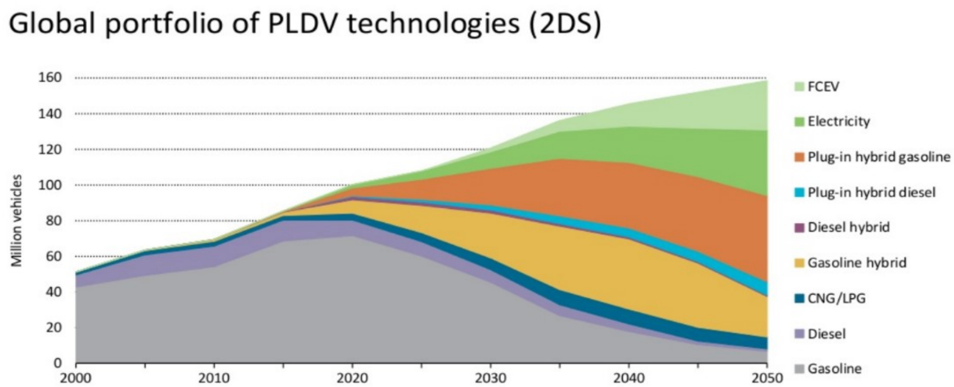

Figure 1-1: Number of Light Duty Vehicles globally forecasted by IEA (2-Degree Scenario)

To counteract the anticipated growth in the number of LDV's on the road, the IEA suggests that vehicle efficiency must improve significantly towards 2050 in order to avoid a rise in the CO_2 footprint of the LDV sector. This is mainly due to foreseen limitations in the amount of sustainably produced biofuels in the future. IEA have found that biofuels only cover about 10% of the global energy demand in 2012. This will not increase significantly if there is no efficiency improvement. However, IEA does predict that vehicle efficiency will improve significantly. With efficiency improvements included, biofuel resources will be able to cover 27.2% of the total demand. This development can be seen in Figure 1-2.[2]

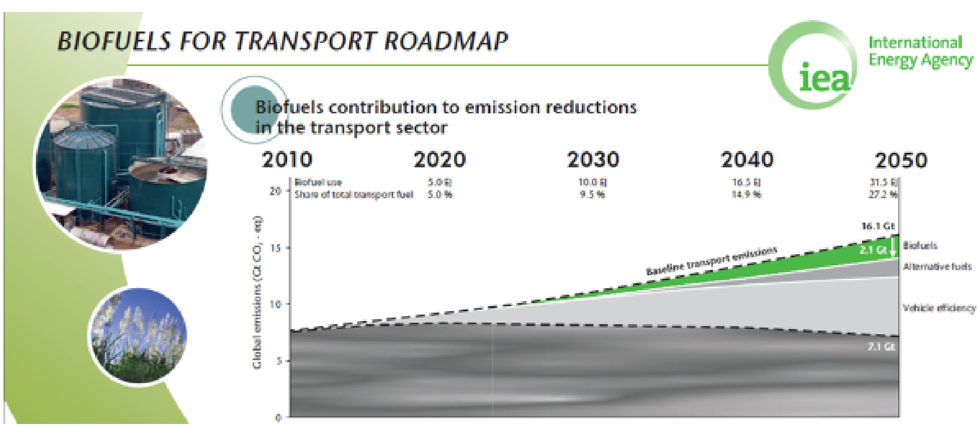

Figure 1-2 Combination of biofuels and vehicle efficiency improvements towards 2050 according to IEA. Source (IEA, 2011)

Looking specifically at LDV's, the IEA together with other organizations have defined the GFEI Fuel Economy Targets, which are shown in Figure 1-3. These goals,

[2] There are many similar predictions by other organisations, and they are regularly updated. Most of these are within the same level as the EIA.

ambitious as they may be, show that a 50% improvement in fuel consumption (volume of fuel used per distance unit) can be considered realistic.

Figure 1-3 Efficiency goals set by the Global Fuel Economy Initiative

2. Overview of the road transport sector in Mexico

Mexican vehicle production sector

Mexico is a large player in the vehicle producing market. In accordance with AMIA, who produced 3.5 million LDV during 2016, Mexico is in the 6th worldwide position as a vehicle manufacturer, the 1st of Latin America and the 4th in the world as a car exporter. Mexico is in 5th place as auto parts exporter, and is the 1st provider of car parts for USA market (Source: OICA[3]).

From 2008 to 2015, the Mexican automotive industry sector contributed to Mexico's Gross domestic product (GDP) with a growth of 58%, the 2nd sector in size, just behind the alimentary industry, closing the gap during the last years (INEGI, 2016).

Nowadays, the economic value of the automotive industry exportations represents 6.7% of the worldwide automotive industry exportations. About 60% of the automotive industry economic activity is concentrated in four states, Sonora, Coahuila, Puebla and Distrito Federal. In addition, from the full industry (light and heavy vehicles and auto parts), the exports represents the 69% of the economic value. (Source: AMIA with INEGI information).

In 2016, the Mexican car production was 3.46 million and growing with an average of 8.2% during the last 6 years. The projected annual grow is 8.6% until 2020. From the total Mexican car production, 2.77 million units was exported and the rest was destined to the local market (i.e. 80% of the production is for non-Mexican markets (AMIA). In Figure 2-1, the LDV Mexican production is showed. The labels represents the exports as total production percentage.

[3] OICA International Organization of Motor Vehicle Manufacturers . http://www.oica.net/category/production-statistics/

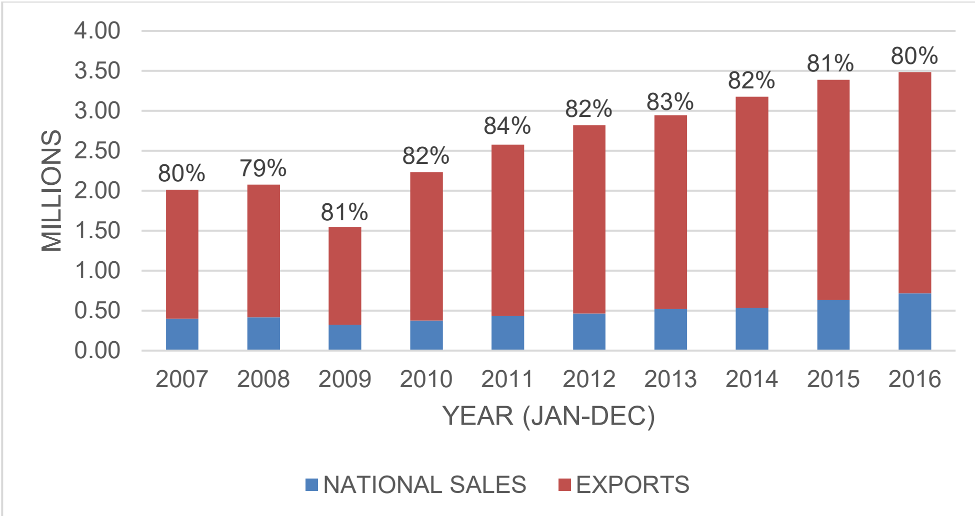

Figure 2-1: Production of passenger cars in Mexico. Source: self-elaboration with AMIA data.

From the total light duty vehicles sales in México (1,603,896 for 2016 year), 45% was produced locally and 55% was imported from other countries. For 2016, the total LDV sales in United States of America was 17.5 million (FORBES, Jan. 2017), almost 10 times the Mexican sales, showing a very different market dynamic between the two countries in size, motorization rate and use full life of the vehicles. In spite of the differences, the 2016 Mexican local car sales growth 18.6 % higher than for 2015, the all the times highest sales increases.

Light duty vehicles imports during 2016 was close to 900,000 units and almost half of these vehicles were imported from Asia, 20% from the TLCAN region and the rest from MERCOSUR and European regions according to AMIA data.

The commercialization of hybrids and electric vehicles in Mexico is starting to grow. During 2016, the sales accumulated to September was 5,495 LDV with 46% of sales in Mexico City and the Estado de México, mainly associated with the exemption to the “Hoy no Circula” local Program and with fuel prices progressive increases. The hybrid vehicles market is incipient, nevertheless, the AMIA claims very high growing rates during the lasts years and especially during 2016. The Mexican industry offers around 18 different models for low carbon technologies (electrical and hybrid vehicles) from different brands.

In the heavy-duty sector, the hybrid and electrical vehicles are almost insignificant with very limited commercial options. In accordance with ANPACT, the total production of heavy-duty vehicles in 2014 was 169,000 units with total exports of 73% of the production and an average growth of 19% during the last five years. The numbers show a similar performance to the light duty vehicles industrial sector, not in size, but in imports-export balance and growth rates. These similarities are associated with the strong dependence of vehicle industry and economics.

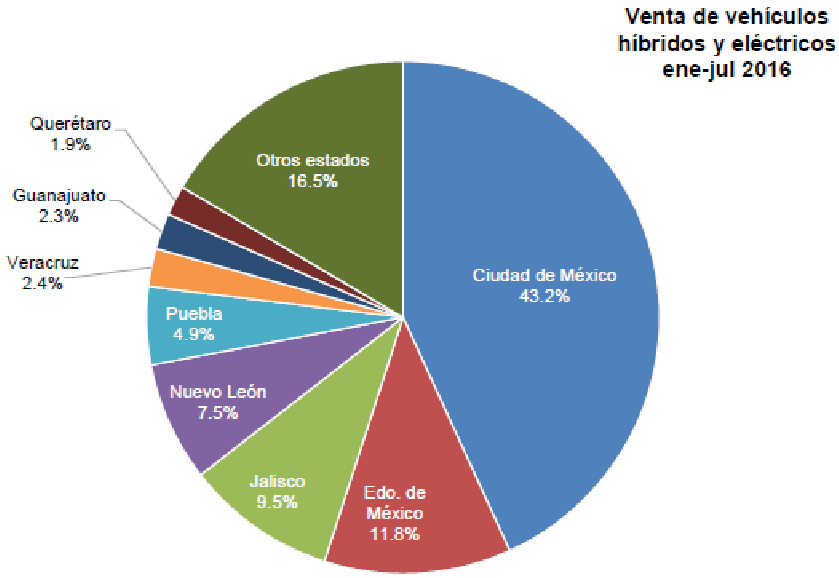

Figure 2-2: Geographical distribution of electric and hybrid vehicle sales. Source: AMIA, July, 2016

Fuels consumption

The main fuels used in road transport in México are gasolines, diesel, and LPG with an average fuel consumption in 2015 of 794, 317.2 and 35.3 thousand barrels a day respectively (Prospectiva de Petróleo Crudo y Petrolíferos 2016-2030, SENER, 2016). Mexico has an important dependence of fuel imports with 41% of diesel and 56% of gasolines imported; this tendency is on a continuous growth.

In accordance with AUTO-GAS (2017), Mexico is one of the biggest LP gas vehicles market in the word, with 250,000 vehicles and represents 2.2% of the total fuel consumed by the national vehicular fleet. About infrastructure for supply, Mexico has 2,150 LPG refilling stations. All of the vehicles consuming LPG were retrofitted from vehicles designed originally to burn gasoline. Three thousand new Compressed Natural Gas (CNG) vehicles using natural gas as a fuel was estimated for 2014 (SENER, 2016).

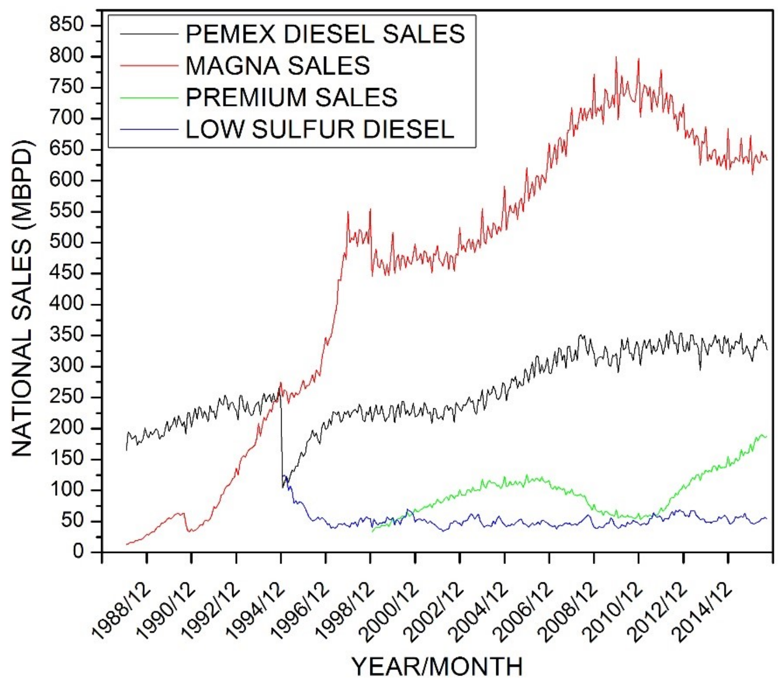

Figure 2-3: Fuel sales per month. (Self-elaboration with INEGI data).

The 2013 light duty fuel economy standards were the first released in all Latin America and establish the standards from 2013 to 2016 model-year vehicles. This last standards are harmonized with the one established by National Highway Traffic Safety Administration (NHTSA) in the United States. Nevertheless, still less stringent than the standard for European Union for 2015 (14.4 Km/l vs. 18 Km/l as average fuel economy standards for gasoline and diesel respectively). Recently Mexico has approved an extension of the actual limits for 2017 model-year vehicles (DOF: 24/06/2016).

At the moment, fuel economy standards for heavy duty vehicles are under development and are expected to be published for June, 2019 i.e., 2020 model year vehicles, in coincidence with the application in México of the EPA 2010/EURO VI emissions standards. The main reason for the delay in implementation of the standards is the absence of Ultra Low Sulfur Diesel distribution throughout the country.

Developments in the Mexican vehicle fleet

The dynamics of the Mexican vehicle fleet has many different components; the most important findings are described below.

Imported used vehicles represent a significant element of the Mexican fleet composition. In some years (2006-2007) the number of used car imported from US and Canada are bigger than the new car sales in Mexico or to the total units exported from México, especially for the period 2005-2008 year, see Figure 2-4.

In the figure, the labels represent the shares of imported used vehicles in the annual car incorporation to the national register. During 2006 and 2007 the number of used vehicles imported was higher than the Mexican sales, never the less, during the last years the participation of the imported used cars was falling. At the end of 2016, the imported vehicles represents only 11% of the new registered vehicles.

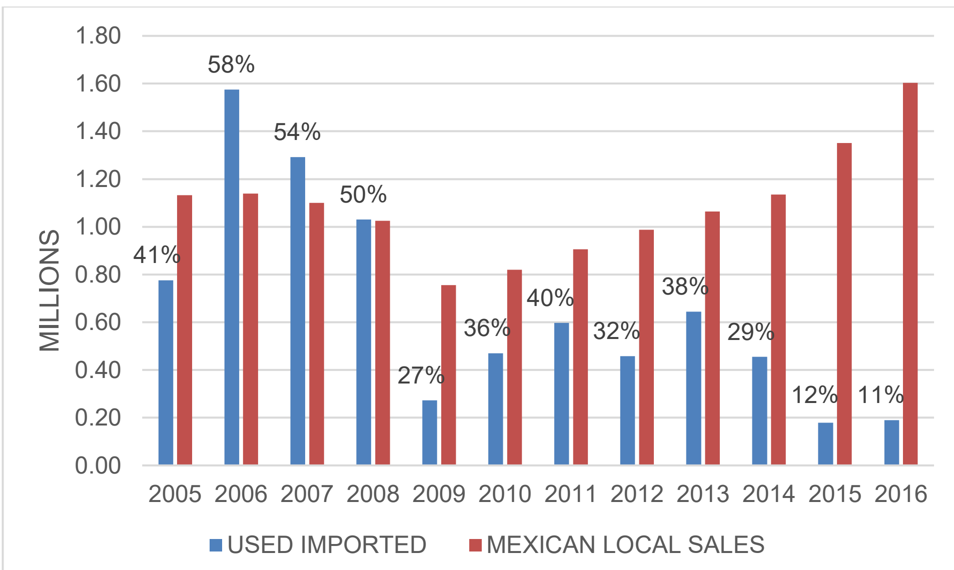

Figure 2-4: New passenger car registrations. New cars and imported used cars. Source: elaboration from AMIA sales data.

The imported used vehicles data by definition has important uncertainties. For example, for 2013 year, the United States International Trade Commission reports 115,000 used vehicles exported from US to México, and the AMIA reports (with SAT-PROCAFIS data) 644,000 used vehicles imported to México in the same period, more than 5 times greater. There is no immediate explanation for this difference in accounting, though.

The used vehicle commercial flow between Mexico and US is influenced by local and federal regulations from both, USA and Mexico; at the same time, are strongly supported by the North American Free Trade Agreement (NAFTA), establishing the obligation for marketing and restricting the sales of latest model vehicles.

The vehicle average age profile in Mexico, for private light duty vehicles is around 13 years, and for heavy duty vehicles around 15 years for trailer trucks, or older (17 years) for the cargo vehicles with gross vehicular weight lower than 3 tons (INECC,2017). In figure 2-5, the average age for different fleet categories is presented.

Vehicle	Average age
Private cars	13
Taxis	6
Van	13
Combi	10
Pickup	19
Truck<3Ton	17
Truck>3Ton	16
Bus	14
Trailer	15

Figure 2-5: Average age for Mexican fleet by vehicle type. (INECC, 2017).

The in-use vehicle National Register shows a predictable tendency and poor dependence in Mexican Economic growth. The national fleet growth by year shows more dependence from imported used cars than from global local sales, suggesting an important influence of mega diverse and low regulated fleet sector (see Figure 2-6).

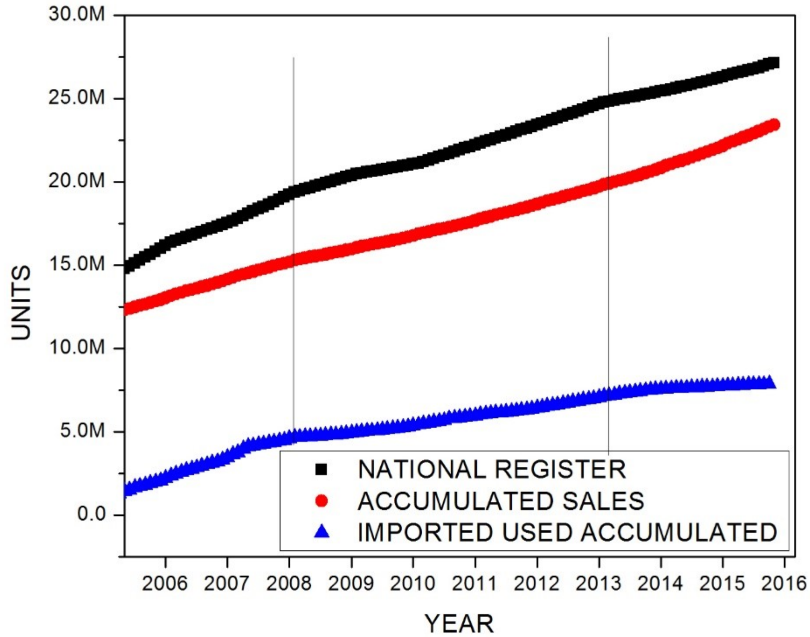

Figure 2-6: Number of light duty vehicles registered in the Mexican vehicle fleet and relationship with local sales and imported used vehicles. Source: Self-elaboration form INEGI statistics

The road transport sector is a major contributor to the emissions of greenhouse gasses and in particular to CO_2 (Figure 2-7).

CUADRO 1 • Emisiones de GEI en 2013 (Gg de CO_2e)

Emisiones totales de GEI (Gg de CO_2e)								
Total: 665,304.92								
Sectores	Total GEI	Participación sectorial	CO_2	CH_4	N_2O	HFC	PFC	SF_6
Fuentes móviles	174,156.53	26.2%	169,863.14	273.16	1,334.66	2,685.58		
Generación eléctrica	126,607.66	19%	125,966.81	110.29	530.56			
Residencial y comercial	25,639.35	3.9%	23,028.00	2,281.06	330.28			
Petróleo y gas	80,455.26	12.1%	49,510.60	30,944.66				
Industria	114,949.19	17.3%	97,864.44	9,910.30	518.70	6,464.06		191.69
Agropecuario	80,169.09	12%	376.99	54,620.30	25,171.79			
Residuos*	30,902.99	4.6%	1,630.11	27,391.44	1,881.44			
USCUSS**	32,424.86	4.9%	31,461.60	633.51	329.75			
Emisiones totales	**665,304.92**	**100%**	**499,701.68**	**126,164.73**	**30,097.18**	**9,149.64**		**191.69**
Participación por gas (emisiones totales)	**100%**		**75.1%**	**19%**	**4.5%**	**1.37%**	**0.0%**	**0.03%**
Permanencias USCUSS ***	-172,997.61	**100%**	**-172,997.61**					
Emisiones netas	**492,307.31**	**100%**	**326,704.07**	**126,164.73**	**30,097.18**	**9,149.64**		**191.69**
Participación por gas (emisiones netas)	**100%**		**66.4%**	**25.6%**	**6.1%**	**1.86%**	**0.0%**	**0.04%**

Notas:
La suma de los parciales puede no coincidir con los totales debido al redondeo de las cifras.
Los Potenciales de Calentamiento Global (PCG100) empleados en este cálculo para los GEI corresponden al Quinto Informe de Evaluación del IPCC (AR5, por sus siglas en inglés) (IPCC, 2013).
Las celdas vacías significan que no hay emisión de este contaminante (o absorción de CO_2).
* Incluye RSU y residuos peligrosos, así como tratamiento y eliminación de aguas residuales.
** Incluye las absorciones de tierras convertidas a tierras forestales.
*** Incluye las permanencias de las tierras forestales, pastizales y tierras agrícolas.

Figure 2-7: Contribution to GHG emissions by category. Source: INECC, 2015.

Fuel quality

During years, the introduction in México of worldwide best available emissions technologies in both, gasoline and diesel vehicles, was delayed due to fuel quality issues. In recent years, this delay is associated with fuels sulfur contents.

Maximum sulfur contents is relevant, because ultra-low sulfur fuels act as a technological trigger for posttreatment devises and are essential for high efficiency NOx catalytic converters in gasoline vehicles and for particle traps, oxidative catalytic converters and selective catalytic reduction in diesels.

In Mexico, fuel quality is regulated by the standard “NOM-016-CRE-2016, Especificaciones de calidad de los petrolíferos”, published in August 2016 and effective since October 2016. As part of this regulation, the specifications for gasolines, diesel and LPG are established. In accordance with the norm, nowadays the gasolines must have a maximum sulfur content of 30 ppm as an average, with a maximum of 80 ppm.

For diesel fuel, the maximum sulfur content in all the country is 500 ppm and 15 ppm in big cities like Mexico City, Monterrey and Guadalajara, in the borderline with USA and in 11 corridors covering 10,000 km. This corridors was designed in accordance with PEMEX production and logistic infrastructure, fuel availability and pipeline distribution network. For December 31, 2018, diesel sulfur content must be 15 ppm in all of Mexico. Nevertheless, it would be advisable to review the law enforcement mechanisms on producing, importing and selling these fuels.

In spite of the availability of ultra-low sulfur fuels in Mexico, in accordance with the Mexican emissions standards, the better commercial available emission technologies (TIER 2 for light duty vehicles and EPA 2010/EURO VI for heavy-duty vehicles) will not be incorporated in new vehicles until some period after ultra-low sulfur fuels full country coverage. This delay is 18 months for light duty vehicles and 6 months for heavy-duty vehicles, these intervals are proposed in order to avoid inventory stockpiling. Nowadays, in accordance with the available information, it is possible to diminish these phase-in periods. Nevertheless, the discussion with automotive industry in order to have these environmental benefits as soon as possible is unavoidable.

Low carbon transport technologies with potential for Mexico

The transport technologies contribute differently to the potential reduction in energy consumption and emissions. For some technologies, the changes occur due to improved efficiency and general improvements in the way the technologies work. Other technologies are newer in the transport sector or are not yet matured to a full market introduction.

In this section, an overview of the potential development in existing technologies is presented together with an overview of the new technologies, which could be further introduced in the local (Mexican) market in the years to come.

Technology options for LDV

Looking at efficiency gains already obtained by the automotive industry it can be verified from Figure 2-8 that CO_2 emissions for new cars in the NEDC, which is proportional to the fuel consumption per distance driven, has already been reduced by approximately 25% since 2000. This is shown with solid lines in the figure. For instance, cars sold in the USA have moved downwards from approximately 204 to 158 g/km equal to 23% from 2000 to 2014 (ICCT, 2015[4]).

Thus, according to official cycle measurements, new cars of today are much better in terms of fuel economy than they were just a few years ago.

Looking at the regional targets for CO_2 emission per driven distance, shown with dotted lines in Figure 2-8, these targets indicate a further 40% decrease of energy consumption for new cars sold in 2025. For instance, USA targets 97 g/km new fleet average in 2025, which is 39% lower than the above-mentioned 2014 figure (ICCT, 2015).

Thus, according to official estimates, new cars in the future will be much better in terms of fuel economy than the cars of today.

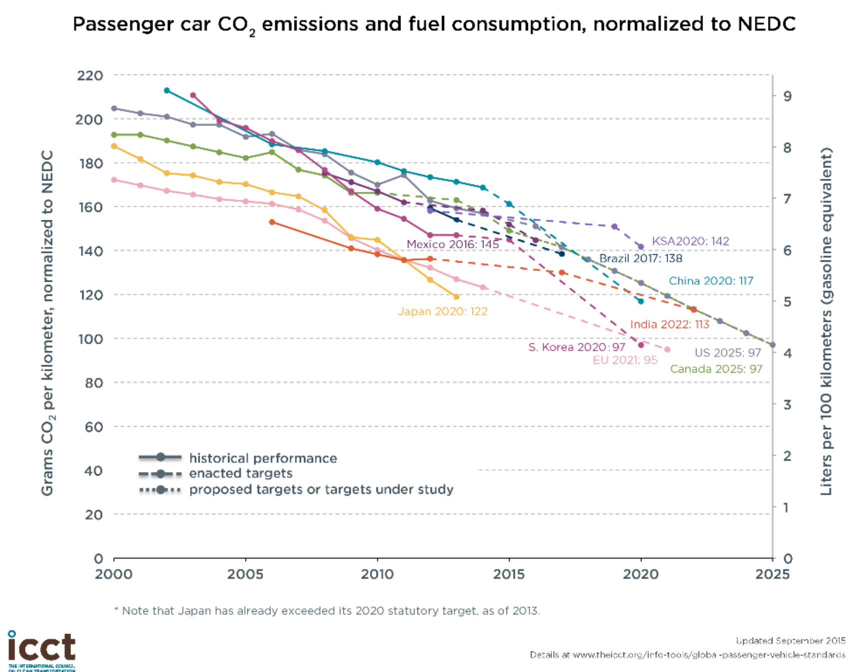

Figure 2-8: LDV fuel economy improvements and targets. Source: ICCT (2015)

What are the technologies that will enable these dramatic efficiency gains?

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[4] http://www.theicct.org/sites/default/files/info-tools/pvstds/chartlibrary/NEDC_CO2_cars_Sept2015.pdf
[5] http://www.fueleconomy.gov/feg/hybridCompare.jsp

First, electrification in different forms will contribute to efficiency. Hybrids generally consume roughly 30% less fuel due to reduced engine idling, recuperation of braking energy and a more optimized engine operation. The US Department of Energy site[5]har prepared an online calculator, which can be used to calculate the costs of the different specific hybrid vehicles with conventional technologies. Therefore, more and more LDV manufacturers are including hybrid technology into their drivelines. This may be in the form of light hybridization, which only supplies a few kW during vehicle launch or a full hybridization, where the electric motors can propel the vehicle in all situations. Many configurations are possible.

The conventional piston engine still has a lot of potential for improvements. Some technologies that are already common are:

- Turbocharging for lighter weight and less engine friction with smaller engine size, also known as engine downsizing.
  The idea of turbocharging is pressurizing and cooling the combustion air before it enters the engine. This allows more air mass to enter the cylinders and thus more fuel can be burned per stroke. This in turn allows a smaller, lightweight engine to produce enough power for a larger vehicle. The smaller engine has less internal friction due to fewer cylinders and smaller lubricated areas and, at the same time, diminishing heat loses. Furthermore, the lighter weight of the engine allows lighter components to be used also in other structural areas of the car. This adds up to a better fuel economy. Durability issues arising from the higher strain on the engine has largely been solved by better manufacturing and improved lubrication and cooling systems. The fuel economy benefit of engine downsizing is said to be 5% to 15% according to the Committee on the Assessment of Technologies for Improving Fuel Economy of Light-Duty-Vehicles. (Johan et al, 2017).

- Direct fuel injection:
  The concept of direct fuel injection has been used on diesel cars already since the 1980's. In the late 1990's the concept also emerged in gasoline cars. Direct gasoline injection means that fuel is injected separately into the cylinder independent of the combustion air stream. Port injection systems inject fuel into the air stream or into a pre-chamber outside of the cylinder. The advantage of direct fuel injection is less heat loss and more precise delivery of fuel into the combustion chamber. Modern direct injection systems can even deliver multiple targeted injections within just a few milliseconds to allow a very precise combustion phasing, allowing different combustion modes i.e.

stratified combustion. The fuel economy benefit of direct injection is said to be up to 15%[5]

- Variable valve timing:
  Intake and exhaust valves of car engines are operated by purely mechanical connections meaning that they normally open and close in synchronization with the engine main shaft. This is only optimal for low speed operation. At high engine speeds, the valve actuation must be offset to allow maximum flow through the engine. In earlier days, the valve train would be tuned to either low- or high-speed operation. Today most car engines have a mechanism that can alter the valve tuning in a least two steps. The fuel economy benefit of variable valve timing is said to by about 5% (Unger et al, 2008, Table 2.7).

- Throttle less operation:
  Unlike diesel engines, gasoline engines are normally controlled by an intake throttle valve, which restricts the flow of air to the engine. This gives rise to pumping losses, similar in effect to a constant engine braking. By letting the intake valves act as airflow controllers the intake throttle valve can be omitted and the throttling loss eliminated. This requires electro-hydraulic valve timing or similar technology. However, it is standard on some engines and the fuel efficiency benefit is said to be around 12% (Unger et al, 2008).

The above-mentioned technologies have contributed to the reductions already achieved by leading engine manufacturers.

Future technologies in conventional engines

Future technologies that are about to enter the market are:

- Cam-less valve actuation:
  Camshafts are used to activate the intake- and exhaust valves on both diesel- and gasoline engines. Even with variable valve timing and throttle less operation, as mentioned above, the engines still rely on rotating cams for basic valve activation. This does not only create mechanical losses and excess weight due to timing chains, sprockets, springs and cam-followers. It also limits the ability of the valves to work independently on the engine main shaft. Ideally, the valves should be completely free to move independently of the main shaft to create optimum compression/expansion ratios at all load scenarios. This can only be achieved with a cam-less valve train. This exists

[5] http://products.bosch-mobility-solutions.com/en/de/powertrain/powertrain_systems_for_passenger_cars_1/direct_gasoline_injection/direct_gasoline_injection_23.html

on prototypes e.g. Koenigsegg, *Qoros Freevalve*, but are not commercially available yet.

- HCCI- and PPC operation
  HCCI is a gasoline-like operation without spark plugs, which can also be obtained in diesel engines. This creates a much cleaner combustion without sacrificing the high efficiency of the diesel engine. Compared to traditional gasoline engines the benefit is up to 30%. The fuel saving benefit is mainly achievable at low load operation, since HCCI is only possible at lean conditions due to knocking issues. Other combustion concepts, such as partially premixed combustion (PPC) seek to combine advantages of premixed combustion with direct injection, to improve efficiency while avoiding knock. The downside is a significant increase in combustion noise and risk of mechanical damages due to an extremely steep pressure curve inside the cylinder. Examples of such technology is seen on the upcoming *Mazda Axela 2018* (HCCI). The fuel requirements for this new technology engines are under development too.

- Variable compression ratio:
  Variable compression ratio is relevant for gasoline engines mainly. It allows the engine to run at high load with a low compression ratio, resulting in high power output at a lower fuel octane requirement, while shifting to a higher compression ratio at lower loads. This allows higher thermal efficiency when running at lower load, which covers most of the operation time on passenger vehicles. Variable compression ratio was demonstrated by SAAB already in 2000 and is now being commercialized by *Infinity on the model MR20 DDT* from 2018 model-year.

Contemporary engines like *Mazda Skyactive-G* (introduced 2011) with direct injection and 14:1 compression ratio and Fiat Multiair (introduced 2010) with electrohydraulic valve train roughly produce a 15% better fuel economy compared to their predecessor engines.

Next generation engines like *Mazda Axela 2018*, *Qoros Freevalve* and *Infinity MR20 DDT* promise roughly 30% improvement over contemporary engines, mainly associated to better air and fuel management.

In combination with other measures such as light weighting, aerodynamic optimization, multispeed transmissions etc. a potential 50% reduction in fuel consumption per distance driven seems quite realistic to be achieved in 2050 compared to 2005. The European *Well-to-Wheels* project (JRC, 2014) have for example projected between 25 and 35% reduction in energy consumption for diesel and petrol vehicles between 2010 and 2020 (or somewhere after 2020, the report is not stating an exact end date).

Electrification

All-electric vehicles and plug-in hybrids offer additionally the option of operating purely on electricity from the grid for longer or shorter distances. This increases efficiency even more, since all-electric, driving consumes roughly ¼ of the energy of contemporary combustions engines. For instance, the *Tesla S* full size electric sedan is rated at 98 MPG equivalent,[6] while a similarly sized sedan *Audi A7* is rated at 24 MPG. A ratio of 4.1:1. Full electric driving however, is not expected to meet all transportation needs due to the limitations on all-electric range. Until battery technologies can provide a better range, the use of ICE as range extender will be usual.

Hydrogen

Hydrogen fuel cell cars are available for leasing now, but the actual cost of the vehicle is much higher than electric cars. The fuel efficiency of hydrogen cars is better than conventional cars, but not on par with the full electric car. Hydrogen cars possess the advantage over electric cars that the range is longer and refueling only takes minutes. The future of hydrogen cars is not predictable at this time. The majority of automobile manufacturers seem to focus on electric cars for the time being, nevertheless, some models like the Toyota Mirai and Honda Clarity Fuel Cell is commercially available in the international market today.

Biofuels

Biofuel (ethanol, biodiesel, and other fuels derived from biomass) have the potential to cover 27.2% of the global transportation energy need in 2050 according to IEA. Long-term focus is on fuels that are not derived from food sources such as sugar, corn, oil crops or grains. Preferably cellulosic raw materials such as straws, wood and fibrous wastes should be used. These are harder to refine, but more sustainable. Alcohols still constitute the bulk of the biofuel market but paraffinic biofuels such as synthetic or hydro treated oils are becoming increasingly popular due to their high-energy content and suitability for current diesel engines.

[6] See for example https://www.fueleconomy.gov/feg/noframes/35980.shtml

Technology options for medium and heavy duty vehicles

Some of the changes in technologies relevant for the heavier part of the transport (buses, trucks and other vocational vehicles) include:

- Idle reduction:
  In the idle condition, the engine is running with no external load. Thus, it uses fuel for no specific purpose. Reduced idling can be obtained through better education of drivers, better auxiliary power units in vehicles, electrical outlets at truck stops and hybrid drivetrains.
- Vehicle efficiency improvements:
  There is a vast number of ways to improve vehicle efficiency. These include things like engine improvements, transmission enhancements, improved aerodynamics, low rolling resistance tires and changes in cargo systems and logistics.
- Low-carbon fuels:
  Many low-carbon fuels are suitable for medium-heavy duty vehicles. The primary options are natural gas, biogas, ignition-enhanced ethanol (E95) and biodiesels. Typically, they represent an on-cost on the vehicle and infrastructure side. In some cases however, savings on direct fuel cost can offset this.

Conventional technologies

Diesel engines typically drive HDV's. Diesel engines are characterized by high fuel efficiency and durability, but also by highly complex emissions reduction systems. This makes diesel systems relatively heavy and expensive to manufacture, but cheaper to run. Therefore, they are best suited for heavy-duty applications.

For the past 20 years, truck and bus engines have developed significantly toward cleaner combustion. This has been done by adding high-pressure injectors, better turbocharging systems, exhaust gas recirculation (EGR), particulate filters and catalytic converters. The fuel economy however, has remained almost constant over the years, because the penalties related to the incorporation of anti-polluting devises (IEA-AMF, 2016). This means that the CO_2 emission of a newer engine is similar to that of an older engine. The main benefit of newer engines is that NO_X and particulate matter emissions are much lower. These emissions are a serious hazard to the public health. For operation within city areas, it is therefore highly recommended to use only the newest US2010 compliant engines, which have both a particulate filter and a catalytic NO_X reducing device (IEA-AMF, 2016).

It is common among truck and bus drivers to let the engine idle when stationary instead of switching it off. This is often done to keep the air-conditioning running while waiting for a new payload, passengers, a ferry etc. Moreover, it is also a common belief that diesel engines work better if they remain on, and it may also be necessary, in order to use a crane or other hydraulic equipment on the truck or keep a container refrigerated. Older or poorly maintained trucks may lose pneumatic pressure in the braking and suspension system if the engine is switched off. Idling does not consume very high amounts of fuel. However, it is advised for all modern truck- and bus drivers to avoid idling and in some cities, prolonged idling is even prohibited. The means to achieve reduced idling is mainly through education of the drivers.

Hybrid

On buses, hybrid drivetrains are becoming more and more common. A hybrid-electric bus is powered by an electric motor, and a smaller than normal conventional internal combustion engine. To achieve heightened efficiency, the battery powered electric motor allows the combustion engine to operate at periods of maximum efficiency. The major components of a hybrid drive system include an internal combustion engine (ICE), a generator, a battery pack, and an electric motor. The most commonly used batteries in hybrid vehicles are lead-acid or nickel-metal hydride. They achieve up to 30% better fuel economy by reducing idling and by using a smaller engine than traditional buses (IEA-AMF, 2016). This is a major benefit in cities with many starts and stops but for longer trips and for trucking it is of little benefit.

Efficiency improvements in current engines

Idle reduction on LDV's and MDV’s is mostly achieved by incorporating a start-stop system, which is commonly available. The benefit of such systems vary with the driving pattern. In heavy city traffic, the system could save 10% or more of the total fuel consumption.[7] On country roads and highways, however, the benefit will be almost zero. The US EPA estimates an average fuel economy gain of 4-5% with start-stop systems.[8]

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[7] E.g. Natural Ressources Canada: http://www.nrcan.gc.ca/energy/efficiency/transportation/cars-light-trucks/buying/16757

[8] https://www.epa.gov/greenvehicles/gasoline-and-diesel-advanced-technology-vehicles

Some manufacturers on vehicles use cylinder deactivation. The fuel economy benefit is up to 10% while driving at low to medium speeds.[9] A realistic average saving would be 4-5 %. Large V8 engines would benefit more than smaller engines.

Aerodynamics is of special interest to the trucking business. On open bed trucks, a tarpaulin can save as much as 5% fuel. Side skirts can add another 1%. Spoilers on the roof can add yet another 1%. MAN Truck & Bus AG has calculated a total of 15% fuel economy improvement by aerodynamic means as shown in Figure 2-9. This is however, only valid on easy highway cruising. In worse conditions, the benefit drops to about 5%.

Variants	Length Change Front & Rear	Paletts [1m Height] Volume [98 m³] const.	Fuel Reduction [Easy highway]
Basis	Basis TGX	68	0%
A	Front :+ 0,8 m Rear : 0	68	- 5%
B Flaps 10°	Front :+ 0,8 m Rear : + 0,6 m	68	- 8%
D	Front :+ 0,8 m Rear : + 1,2 m	70	- 10%
F Boat tail	Front :+ 0,8 m Rear : + 2,7 m	70	- 15%

Figure 2-9: Aerodynamic potential of trucks at easy highway cruising (MAN Truck & Bus AG)

Programs such as the US DOE Supertruck Challenge have demonstrated that it is technically possible to improve the freight fuel efficiency by at least 50% compared to a conventional truck.[10] This can be done by a combination of means, some of which relate to the engine and some of which relate to the rest of the vehicle. Turbo compounding on the engine as a way to recover heat of the exhaust stream, can improve fuel economy by 6.5%.[11] Common rail injection system and other engine refinements can add another 2-3%. Combined with other engine improvements the thermal efficiency can be raised from currently 38% to at least 50% as shown in Figure 2-10. This translates to a 24% reduction in fuel consumption.

9 http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/pdf/transportation/fuel-efficient-technologies/autosmart_factsheet_4_e.pdf

10 https://energy.gov/eere/articles/supertruck-leading-way-efficiency-heavy-duty-long-haul-vehicles

11 http://articles.sae.org/14699/

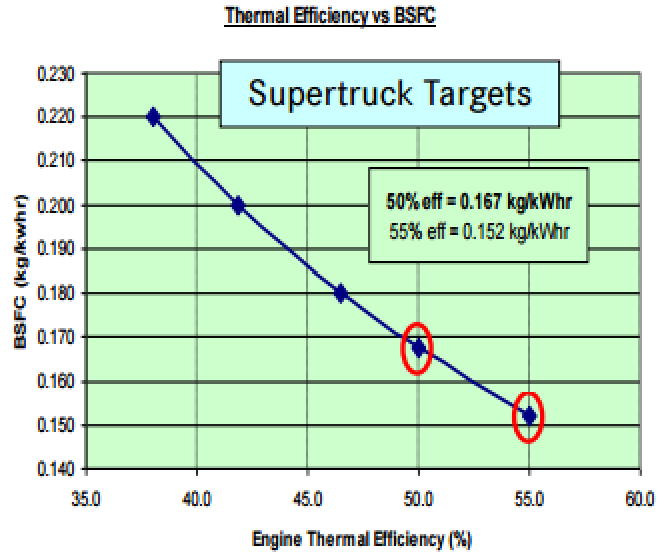

Figure 2-10 Engine efficiency goals from DOE Supertruck (Daimler)

Non-engine modifications include brake energy recuperation; use of lightweight materials such as aluminum and carbon fiber, predictive gear shifting. An overview on non-engine (vehicle side) technologies is shown in Figure 2-11.[12] It can be seen that aerodynamics and rolling resistance are main contributors to increased vehicle efficiency. Current low rolling-resistance tires can reduce fuel consumption by 2% and prototype tires have reached up to 6%.[13]

[12] https://energy.gov/sites/prod/files/2014/03/f13/deer11_sisken.pdf
[13] e.g. www.dimnp.unipi.it/guiggiani-m/Michelin_Tire_Rolling_Resistance.pdf

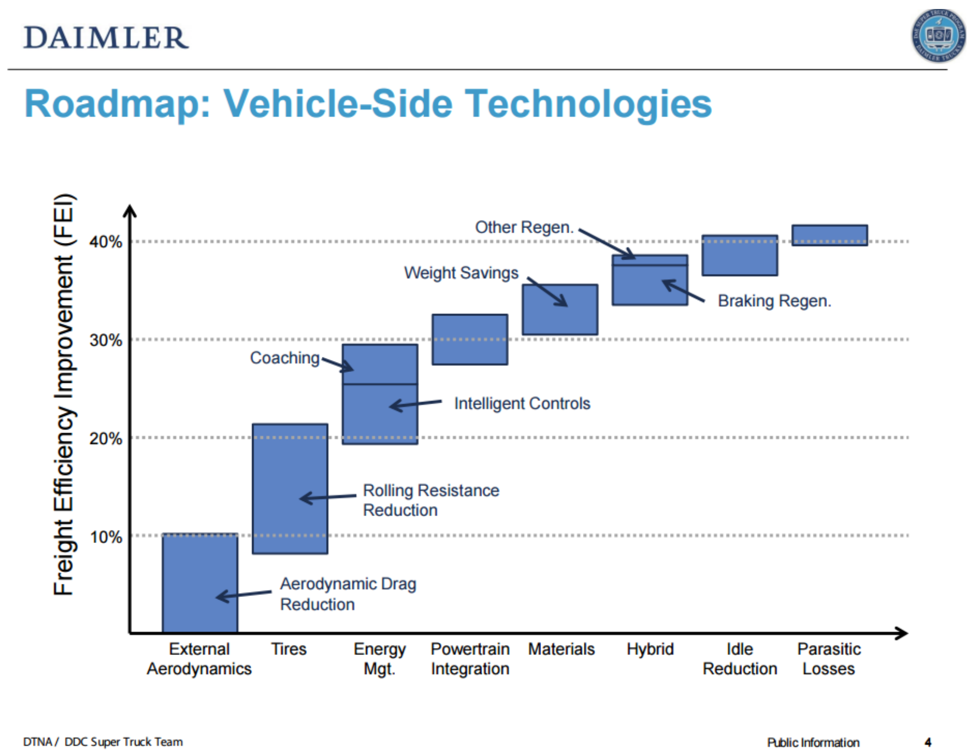

Figure 2-11 Non-engine improvements for heavy trucks (Daimler)

The most direct and efficient way to improve the freight fuel economy of a truck is by adding capacity. This can be done by using a double deck truck bed, which allows goods to be more efficiently stacked. It can also be done by adding length to the truck, e.g. by adding an extra trailer. This is commonly known as a road train or a modular system. These kinds of arrangements are known to potentially save 15–20% fuel (DTL, 2015[14]). Even without physical modifications, truck freight can often be optimized just by thorough planning and combination of e.g. heavy and light objects, so that the trucks capacity is utilized optimally both, in term of weight and volume. Savings of up to 17% are achievable this way (DTL, 2015). To use this options, it is necessary also to consider the potential impacts on road transport safety due to the longer vehicles. They must e.g. comply with the safety requirements set up for the freight road transport.

[14] http://gronberegner.teknologisk.dk/Katalog.pdf

Alternative fuels

There are a number of alternative fuel options for HDV and MDV that could reduce the carbon footprint. For buses, the prevalent choices are electric or natural gas. Both are suitable in cities. Natural gas will only yield a minor reduction in CO_2, because natural gas engines are less efficient than diesels. However, by substituting natural gas with biomethane the CO_2 reduction becomes very significant. Biomethane is produced by removing CO_2, water and other impurities from biogas, thereby producing high quality methane. If biomethane is not physically available at the place of usage it is common to rely on trading schemes where biocredits are exchanged between parties (such bio schemes are introduced in several European countries for e.g. biogas and the European CO_2 emission-trading scheme).

Electric buses are becoming more and more common in some markets. Battery electric buses are replacing the traditional trolleybus. These can have a range of up to 400km per day[15] and do not depend on overhead wires. Due to the current high cost of batteries and infrastructure however, it is feasible to use smaller batteries in combination with quick charging facilities at certain bus stops. Such a solution is seen in Figure 2-12.

Figure 2-12 Battery electric bus with top mounted quick charging unit (Source: Volvo and Siemens)

[15] http://insideevs.com/byd-electric-bus-test-results-in-canada/

If battery electric buses or natural gas cannot be used (e.g. because the required infrastructure is not available,) then the best alternative, (in terms of smog prevention) is to go for US2010 compliant diesel buses. This will reduce toxic emissions and smog formation significantly. Retrofit upgrades are also available for some buses as alternative to buying new vehicles.

Blends of diesel and biodiesel, hydrogenated or synthetic diesel, is possible with practically all diesel engines. Small modifications may be required to run 100% biodiesel on some engines, while hydrogenated or synthetic diesel fuels can usually be run without any concern at all. The important thing to notice is the feedstock, which should be produced in a sustainable manner observing a life cycle assessment, including factors such as indirect land use (ILU).

3. Low carbon transport technologies

In this catalogue, the focus is on known technologies and technologies that have a potential for being market ready within the next 15-20 years. Most of the technologies are either already introduced to the market (although perhaps only in a few variants and not yet by all vehicle manufacturers) or are being demonstrated to the market in different places.

A distinction is made between the fuel and the vehicles. Many vehicles can run on both conventional fuels and biofuels in some blend without requiring changes to the engine or vehicles. Other fuels, such as electricity and CNG however, require specific engines and vehicles. Hence, the technologies chosen to be included in the technology catalogue are within:

- Conventional diesel and petrol engines (in various generations)
- CNG fueled vehicles
- Electric vehicles
- Hydrogen fuel cell vehicles
- Hybrid vehicles

As already mentioned, biofuels are also a main component in future solutions to the CO_2 reduction agenda. However, in most cases biofuels are produced in qualities, which can be used in conventional engines (diesel and petrol vehicles and as biogas). There may be some requirements to upgrade the engines to accommodate higher blends (such as the ethanol-fueled vehicles). Hence, for each type of vehicles it is further outlined which biofuels the vehicle can use and in which concentration.

Fuel	Mode	**Road-passenger**			**Road-freight**			**Buses**		
	Range	Short	Medium	Long	Short	Medium	Long	Short	Medium	Long
Diesel										
Gasoline										
Natural gas	**LNG**									
	CNG									
	Bio-methane									
Electricity										
Hydrogen										
Biofuels (liquid)										

Table 3-1: Alternative fuels and their use for different transport sections. Source: European Group for Alternative Transport Fuels (2015)

This section elaborates a little further the general description of the technologies outlined in the previous chapter by considering short overviews and information about the following aspects[16]:

- *Technology outline*. A short description of the specific vehicle technology. What is it, how does it work and particular beneficial or critical issues
- *Maturity*; e.g. how close is the technology to be available in a mass market introduction; what is the current availability, in which markets have the technology been introduced
- *What are the prospects for the coming years 2020, and 2030 perspective*. What do international sources believe the market future for the technologies are.
- *Fuel sourcing*:
    - Fuel availability today and in the future
    - Does the technology require a dedicated (new) infrastructure to be deployed
- *Technology perspective* including opportunities and barriers for adoption in Mexico.
- *Which road transport sectors the technology is applicable for*. Based on the technology outlooks, which sectors are considered to be the main areas where the technology can be used.

Not all elements are covered to the same extent, but inputs are covered based on relevance for the specific fuel.

The section includes the following technologies:

- Natural gas and biomethane
- Battery electric vehicles
- Hybrid vehicles
- Hydrogen fuel cell vehicles

Natural gas and biomethane

Introduction

Gas extracted from underground reservoirs, both on land and below the seabed, is commonly named natural gas. The natural gas is located in porous geological layers, often as the lightest fraction on top of oil reservoirs. It is also recovered from shale formations by fracking, a method that fractures the otherwise impenetrable shale layers in which the gas is trapped, such that the gas can be extracted.

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[16] The section does not present all details, but aim at giving an overview. For the details the different referenced sources should be consulted.

Today, most natural gas comes from large offshore production sites. While Europe is mainly supplied by Russian inland gas fields, the US and South America receives most of their natural gas from offshore sites such as Qatar in the Middle East. Large volumes of natural gas is transported from the production sites in liquid state as LNG (liquefied natural gas), in LNG carriers with capacities up to 270.000 m^3. The gas is sometimes transferred, stored and redistributed in liquid state to end consumers, but most of the gas received from LNG carriers is evaporated and distributed in pipelines in the receiving countries (EGFTF, 2015).

Biogas is a methane rich gas, which can be produced from almost any kind of biological material such as energy crops, agricultural wastes and residues, animal manure, the organic fraction of municipal waste, sewage sludge, etc. The most common production method is biological degradation of the biomass (anaerobic digestion). .

Properties of CNG and LNG

Raw natural gas contains mostly methane but also a minor fraction of light hydrocarbons in the C2 to C4 range, such as ethane, butane and propane. The gas also contains water, nitrogen, CO_2 and trace amounts of various other impurities. In the refining of natural gas, the content of light hydrocarbons is regulated to meet the relevant specifications, while impurities such as CO_2, water, nitrogen etc. are almost completely removed.

Raw biogas is composed of methane, CO, water and various undesired byproducts resulting from the biological processes, such as hydrogen sulfide and in some cases siloxanes. As with natural gas, biogas must be cleaned (upgraded) to meet specifications before it can be injected into gas grids or used as engine fuel. Cleaning removes components containing Sulphur, CO_2 and water in different process steps. As biogas does not contain other hydrocarbons than methane, upgraded biogas is almost pure methane, whereas cleaned natural gas may contain substantial quantities of ethane, butane and propane. These differences are important, as the gas composition has a direct influence on the combustion process in the engine.

Most natural gas is transported in liquid state from the production sites. The liquefaction process requires that both water and CO_2 content be reduced to 50 ppm, since these components will otherwise freeze and block the process equipment. The process also removes mercury, hydrogen sulfide and other sulfur components, which are aggressive to the process equipment. Hydrocarbons are also removed by condensation, except ethane.

It is important to note that LNG does not contain odorants, such as Mercaptans. Therefore, leaks of LNG will not be detectable by smelling. It is however required that odorant is added when vaporizing the gas for grid injection or use in CNG vehicles.

Disregarding the physical origin of methane (fossil, biomass or synthetic), it must comply with the relevant specifications according to the intended use.

Specifications for natural gas as automotive fuel

The specifications for gas in transportation must follow the standards currently being developed by the DIN project committee CEN/TC 408, once these standards are approved. The regulation covers natural gas and biomethane for use in transport and biomethane for injection in the natural gas network. Two document parts are released:

Part 1: Specifications for biomethane for injection in the natural gas network. DIN EN 16723-1 (2017-01) (standard).

Part 2: Automotive fuel specifications. DIN EN 16723-2 (2014–06) (draft standard).

The methane number describes the knock resistance of the natural gas in a spark ignited engine – higher is better. Methane has a high knock resistance and is assigned an index of 100. Hydrogen has a low resistance and is assigned an index of 0. A methane number of 80 thus corresponds to a mixture of 80 % methane and 20 % hydrogen. Calculation of the methane number based on the composition (higher alkanes, CO_2 etc.) is possible with online calculators.

Most engine manufactures state the rated engine power for a given methane number – e.g. 80. The power rating may decrease linearly with the methane number, due to engine knock limitations. A lower limit for the methane number may also be stated.

Fueling and storage of natural gas in vehicles

The technical committee ISO/PC 252 under the International Organization for Standardization has developed standards for natural gas fueling stations. These standards are:

- ISO 16923:2016 Natural gas fueling stations -- CNG stations for fueling vehicles
- ISO 16924:2016 Natural gas fueling stations -- LNG stations for fueling vehicles
- A separate standard applies to the CNG vehicles nozzles and receptacles:
- ISO 14469:2017 Road vehicles -- Compressed natural gas (CNG) refueling connector

- In the US, the standard NFPA-52 covers natural gas vehicle safety standards.

CNG is usually stored in cylindrical pressure tanks at 20-25 MPa (200-250 Bar). The tanks may be made of steel, reinforced with carbon fibers or all fiber composite constructions, the cylinders are chosen in accordance with best price-lower weight criteria. Several tanks are usually connected in parallel to reach the desired fuel capacity on large vehicles. In passenger cars, a single pressure tank is usually located behind the rear seat.

The density of compressed methane at 25° C / 250 Bar is 215 kg/m^3. With a higher heating value of 50 MJ/kg, the energy density is 10.7 MJ/L.

LNG is stored onboard in highly insulated cryogenic tanks at atmospheric pressure at a temperature some degrees below -162° C. As the LNG will slowly heat up and reach its boiling point at -162° C after fueling, LNG is best suited for vehicles in long haul transportation, or other operating patterns, which can ensure a steady consumption. The boil off gas (BOG) is normally supplied to the engine through the fuel system, but may be vented through a burner as a safety measure if it cannot be used in the engine.

The density of pure liquid methane is 422 kg/m^3. With a higher heating value of 50 MJ/kg, the energy density is 21.1 MJ/L.

Engine Technologies

Natural gas and biomethane can be utilized in both spark ignited and compression ignited engines.

In spark-ignited engines, natural gas is introduced at low pressure in the inlet manifold and ignited by a spark. The engine may run stoichiometric as is normal for gasoline engines. Engines of this kind may be designed to run on either natural gas or gasoline, in which case they are called bi-fuel engines, nevertheless, the bi-fuel engines need to have low compression ratio in order to use gasoline as a fuel, losing the advantages of the natural gas high knocking resistance.

In large spark ignited engines, lean burn combustion can be used for more efficient load control, as load is regulated partly by gas admission, partly by throttling the air inlet. Turbocharging the engine increases the specific power. Spark ignited engines are however not as fuel-efficient as compression ignited engines.

Compression ignited diesel engines can be designed to operate with natural gas combustion, in a concept called dual fuel. Natural gas is supplied to the inlet manifold and ignited by a small quantity of injected diesel. At high load, less than 10 % of the fuel energy is injected as diesel. The dual fuel engine does usually not support combustion of natural gas at low loads, in which case it switches to ordinary diesel operation. Dual fuel engine technology is so far reserved for heavy-duty engines. With LNG storage tanks, dual fuel trucks can extend their range on natural gas substantially over traditional pressure tanks. LNG is thus preferable on long haul operations.

LNG engines can present some fuel metering issues due to the complexity of double fuel management system.

The next generation of engines will likely be equipped with high-pressure direct injection of both natural gas and diesel. In this concept, a combined injector will supply a stratified injection of natural gas, which is ignited by a simultaneous diesel pilot injection. This approach almost eliminates the emission of unburned methane, which is a downside of manifold injected engines. It also enables a high compression ratio like normal diesel engines, which contributes to a higher efficiency.

Maturity of NG engine technology is relatively high with particular research needs regarding robust direct injection and ignition systems for homogeneous and stratified combustion (DG MOVE 2015[17]). In case of lean burn approaches specific developments will have to be addressed to the DeNOx after-treatment, the conversion of current modern diesel engines into NG engines with minor hardware modification, gas quality sensors for monitoring gas composition variations and compatibility of lubricants with gas engine technology according to (DG MOVE 2015).

It is also possible to retrofit spark ignited (bi-fuel) and compression ignition engines (dual fuel) to run on natural gas.

Use of CNG as fuel in passenger cars, medium and heavy duty segment

Internationally the natural gas vehicles and all their components are mature and fully OEM-developed. CNG is used in passenger cars, buses, trucks and other vehicles in many countries. As of 2015, the top 10 countries have more than 20 million registered vehicles together. The leading country is China with more than 4 million NG vehicles, followed by 9 other countries in the Middle East region and South America. Nevertheless, in South America the use of natural gas vehicles is related to economic reasons and not to environmental ones. In Mexico, most CNG fueled

[17] *State of the art – alternative transport fuels. Report prepared for the Expert Groupd of Future Transport Fuels*. DG MOVE June 2015.

vehicles are retrofitted, though, since presently this is a cheaper alternative compared to an OEN produced CNG vehicle.

Although this statistic includes both CNG and LNG[18] vehicles, the LNG vehicles is only a minor fraction of the total. The CNG technology is still the most common in new vehicles, as it is cheaper and thus most suited for use in smaller vehicles. The refueling infrastructure is also less complicated, since producing and fueling CNG is not as demanding as producing and transferring cryogenic LNG.

European manufacturers started to offer CNG passenger cars in the 1990´s. The engine technology has been constantly improved since offering a comfortable driving range of up to 500-900 km on CNG (plus reserve petrol) depending on vehicle configurations and well beyond 1.000 km total mileage, when also considering the petrol reserve tank. The technology is based on spark-ignition mono-fuel or bi-fuel engines (using gas as main fuel and only switching to the petrol reserve when the CNG has been used) and can also be used in compression ignition engines using diesel for ignition and gas as the main fuel (dual fuel and high pressure direction injection technology).

The technology applied on the gas truck engines from IVECO (100% gas) demonstrates the stoichiometric combustion with a three way catalyst can reach the Euro VI limits, even when considering low temperature cycles. Thanks to LNG/BIO LNG tanks fitted on the trucks, the energy density of natural gas and storage capacity is 5 times higher than for CNG. All these qualities apply also to Liquid Biomethane (bio LNG) or mixtures thereof with natural gas.

Use of LNG as fuel in the heavy duty segment

New long haul trucks designed for using LNG as fuel are typically fitted with dual fuel engines. Typically, they will use the LNG first and then continue on diesel if LNG is not available on route.

In June 2016, a few Dual fuel trucks designed for LNG were available, the Iveco and Scania. Volvo has previously marketed and sold trucks (FH Methane Diesel) for Euro V, but not Euro VI. Solbus makes a bus model in two variants (Solcity and Solcity 18) for LNG.

The use of LNG is becoming an important demand from the fleet operators, and development of the necessary infrastructure, is under way with significant support from the CEF transport funds in the EU. High customer acceptance and satisfaction, two inherent objectives of the project, will ensure a strong LNG truck penetration all

[18] Liquified natural gas

around the Corridors in the coming decades, therefore reducing oil imports and CO2 emissions at the same time. During the coming years the use of Euro VI methane/diesel solutions will further improve the vehicle offer of high horse power (>400 HP) applications.

Refueling infrastructure

The LNG Blue Corridors project

The LNG Blue Corridors project is supporting the development of the Euro VI technology, both, in dedicated gas and Dual-Fuel engines aiming to demonstrate that LNG trucks with significant higher range when compared to CNG be a suitable replacement fuel for diesel at large scale. However, the state of the art of gas engine performance has an output of maximum 340 HP and 1300 Nm. Long distance transportation, as demonstrated in the project in real operation and thanks to the close cooperation with several fleet operators, which take part in the project, will demand more powerful engines above 400 HP. New engines (both spark ignition and compressions ignition using HPDI) are currently under development and will be ready for 2017/2018 (LNG Blue Corridors Project[19]).

The corridors will establish LNG fueling in some main transport corridors in Europe. In North America, until now USA and Canada have initiated test with dual fuel (based on LNG) heavy-duty vehicles. The LNG is therefore not present in Mexico today.

CNG fueling stations

CNG cars require a separate fueling infrastructure. Such an infrastructure does not exist nationwide in Mexico today. The places to fuel CNG vehicles are mostly privately operated fueling places used for own vehicle fleets. The fueling stations can receive CNG through pipelines or CNG can be trucked and put into compressed tanks at the station. It is in this way it is possible to achieve a national coverage, nevertheless inefficiently.

Prices

The additional cost for gas vehicles is mainly determined by the CNG and LNG storage capacity. While passenger cars have a premium of 25,000-78,000 $MX versus the equivalent petrol version (more or less same price range as the diesel version), the extra investment in a CNG bus would be around 540,000 $MX compared with conventional diesel technology and the incremental cost for a LNG HDV compared with a regular diesel fueled HDV is estimated at approximately 540,000-750,000 $MX, depending on storage capacity and engine output. (NGVA, 2015).

The infrastructure needed to fuel CNG cars can be fed from the existing natural gas grid. In this case, a compressor with the capacity of reaching a final pressure of 200 bars must be installed, and the dispensers. The total cost of this facility would be between 4.3 million $MX and 6.5 million $MX depending on the compression capacity of the installation (normally 300-500 m^3/h).

Provided the station would not be in the proximity of a pipeline, the laying of a natural gas pipeline connection to the station would become necessary and can vary depending on land characteristics (6,500-13,000 $MX /meter). In the case of a CNG depot station for buses or garbage trucks, the average investment for a single station will be around 21 million $MX, due to the much higher capacity and storage needed.

This type of infrastructure supplying LNG can also supply both liquefied and compressed natural gas and biomethane. It has to be fed with liquefied natural gas via HD transport tankers.

LNG stations or L-CNG stations (also depending on capacity and size) would be in the range of 400.000-500.000 Euro for standard LNG station. Higher costs would apply when also taking into account acquisition of land, permits, etc. The upcoming standardization of natural gas filling stations will have a significant impact on bringing down costs, as so far different LNG pressure levels have to be respected due to different existing technologies in the market, which can lead to substantially higher investments. It would be necessary to install a stationary LNG tanker to accumulate and feed the installation, a transfer pump to convert LNG into CNG (only in the case of L-CNG), and the dispensers. The cost of the stationary tanker and the transfer pump is similar to the cost of a compressor. The maintenance of LNG/L-CNG stations would however be lower than in CNG stations.

Perspectives of natural gas implementation

The potential to further decarbonize is significant, as existing engine technologies are based on gasoline and diesel engines, which are not yet fully optimized to run on natural gas, pure or blended with biomethane. Consequently, further efficiency gains are expected for light, medium and especially for heavy-duty vehicles in the next engine generations and years to come.

Methane, blended with biomethane, offers the quickest and most cost efficient way for automotive manufacturers to lower their fleet's CO_2 emissions. However, OEM manufacturers could get more out of the high-octane fuel natural gas, which could enable dedicated engines when purely operated with natural gas, since higher compression ratios can be used. To this aim, there are first results and an ongoing trend to achieve further improved energy efficiency when adopting the turbo-charging and direct injection, which can accommodate to the best boost pressure curve both when running on both CNG/biomethane and gasoline.

In addition to that, efforts in areas like friction reduction, heat management, and combustion optimization have the potential to achieve overall efficiency gains of 10% or more, which add to the powertrain benefits when using natural gas (DG MOVE, 2015). Downsized gasoline powertrains, using turbocharger is the perfect way to achieve a high level of performance with low displacement engines. Research will strongly focus on further optimization of HDV gas engines used in buses and trucks.

Future solutions will include optimized gas engines and hybrids using methane (e.g. city buses in Madrid and Malmö and some LDV are already existing), but the lack of CNG refueling infrastructure still demands the co-existence of three fuels (petrol/diesel, gas and electricity), producing some maintenance and operative inconveniences. Due to the lack of room to lodge the relevant storage systems in nowadays vehicles, it is fundamentally important that vehicles should be running on gas exclusively, before CNG-hybrids will be commercially feasible. Therefore, the focus on improving the methane refueling infrastructure will facilitate the expansion and optimization of natural gas vehicles for both passenger and freight transport on short, (urban and regional), mid (inter-city and countrywide) and long distance (cross-border and heavy goods) transportation.

The state of the art technology is mature for the dedicated natural gas engines in vehicles. For medium/long distance and heavy-duty transport, the LNG Blue Corridors in Europe are currently demonstrating the new Euro VI technology.

Regarding biomethane, the main barriers to market penetration are the higher cost of biomethane in comparison with natural gas, the delays in the adoption of the standard being developed by CEN/TC408 for natural gas and biomethane for use in transport and biomethane for injection in the natural gas grid.

Hybrid electric vehicles

Introduction

Hybrid electric vehicle (HEV)

HEV are vehicles with a combustion engine combined with electric motor and battery energy storage. The electric motor may provide propulsion at low speeds and assist the engine at peak power demand.

The battery pack is charged autonomously while driving and braking, but cannot be charged from external power sources

Motor technology

Parallel hybrid

Both electric motor and engine can supply power to the transmission simultaneously. In some configurations, the electric motor powers the wheelset not powered by the combustion engine. Typically, the electric motor is quite small and is mainly used for power assistance and regenerative braking. The battery capacity is also quite small.

The main advantage in this hybrid configuration is a better exploitation of the combustion engine and the benefit of regenerative braking and the extra power available when both power sources are engaged to the wheels.

Series hybrid

The combustion engine functions solely as a power generator for the electric engine, and cannot be used to power the transmission directly. Typically, a small combustion engine is used in combination with a more powerful electric motor and a moderately sized battery pack.

The main advantage of this hybrid configuration is the ability to run on the electric motor and batteries only, as the engine is only started once the battery needs recharging. This is useful in city and urban driving, in particular when batteries can be charged by external power sources.

Power-split hybrid

This hybrid concept has a transmission that allows the combustion engine to be used either as the primary engine in parallel with the electric motor, or as a generator for the same motor. The concept combines most advantages of both parallel and series hybrids. The cost is however increased by the complexity required in the transmission.

Hybrid electric vehicles constitute a significant trend in global auto manufacturing. Hybrids, like ordinary vehicles, rely on a combustion engine, which uses fuel to generate propulsion energy. However, it also benefits from a rechargeable battery and one or more electric motors. The battery is not charged prior to driving, but rather charged *during* driving, for instance by capturing some of the braking energy that would otherwise be wasted. The battery can also be charged by putting a little extra load on the combustion engine, when it is working at optimum RPM. This requires only very little additional fuel which is more than compensated for when the car is moving slowly or at standstill, because the combustion engine can then be switched off completely. All of this is done automatically.

Plugin Hybrid Electric Vehicle (PHEV)

There is also a transition technology between hybrids and electric LDV's. These are called Plug-in hybrid electric vehicle (PHEV). The main differences between plugin hybrids and normal hybrid vehicles are that the battery can be externally charged and that the battery is typically much larger compared to the engine charged battery in the hybrids. This also means that plugin hybrids largely are used as electric vehicles with a conventional range extender.

PHEV are typically an electric vehicle with a combustion engine. Most of these vehicles can be operated with a battery energy storage that is slightly more limited compared to an electric vehicle, because the auxiliary combustion engine extends the range. The electric motor provides the propulsion and the combustion engine complements the battery, when the battery is closer to being empty. The different PHEV that have been introduced to the market until now varies with the size of the battery and the size of the engine. Some brands have chosen only to have very limited auxiliary fuel tanks and just operate as a simple range extender to reduce the range anxiety. Other brands have chosen to limit the battery size even more and then have a larger fuel tank. The propulsion of these latter versions are more like the normal hybrid vehicles and can only operate in limited distances and speeds as a pure electric vehicle.

The battery pack is charged autonomously while driving and braking, and may be charged from external power sources.

Refueling and recharging

Hybrid vehicles do not require a new fueling infrastructure since they use conventional fuels. However, the plug-in hybrids are by construction electric vehicles and therefore require access to recharging. In this sense, they are completely similar to the electric vehicles, although they most likely do not need as many recharging possibilities in the public domain due to their longer operating rang due to the conventional engine.

Prices

Looking generally at the prices of vehicles introduced in the US market a price difference around 10% is found. The fuel consumption on the hybrid version is 35% lower in city and 20% lower on highways according to EPA figures.

Hybridization is also used in MDV and HDV vehicles in more and more of the vehicles being introduced to the markets. For these vehicles the technology have perhaps a larger potential since, the costs of these vehicles are higher and the additional costs for the electric engine is relatively smaller compared to passenger cars.

Hybrids that are more economical are also available on the mass-market and the cost of a hybrid car is only slightly higher than a standard automatic. The fuel economy benefit of a hybrid LDV is about 25% on average compared to a standard gasoline engine. In total INECC (2016) estimates that the total cost of ownership over a 15 year period is about 40% higher in a hybrid compared to a gasoline LDV.

Perspective

There are very few barriers to further introduction of hybrid vehicles in Mexico as they use existing fuels and fueling infrastructure as mentioned above.

Since the 1990's where the first hybrid cars were introduced, hybrid technology has matured into a reliable and well proven technology, which is certain to benefit the LDV technology for years to come. Luxury and high performance cars have long been using Hybrid technology to obtain a more silent ride and/or a higher peak power output. For the next years hybrid technology (without external charging possibilities) will become more and more common in conventional cars to improve fuel economy. Hybrid technologies are also finding their way into medium and heavy-duty vehicles as well as buses, although still in rather few numbers.

Plug-in hybrids are still a relatively new technology. One of its main features is that it overcomes the range barrier, which is still considered a problem for most of the electric vehicles. It is therefore a likely alternative in the coming years until full-electric vehicles generally do not have a range barrier.

Battery electric vehicles (BEV)

Introduction

Electric LDV's constitute a significant trend in global auto manufacturing. In some markets, BEVs comprise a rather large market share of new vehicles sold, with Norway as the leader with around 10% of new cars being BEVs. Unlike ordinary cars, they do not rely on a combustion engine, which uses fuel to generate propulsion energy. Instead, it uses a rechargeable battery pack and one or more electric motors. The battery is charged prior to driving and charge is partially sustained during driving, for instance by capturing braking energy. The battery can be charged at home or at public charging stations. Usually a home overnight charging is the most economical, but the batteries can also be charged rapidly if needed for a sustained trip. The time for charging has dropped significantly in recent years and is now about 20 minutes. Technology development moves very rapidly in the field of batteries so one can expect a significant breakthrough for the battery electric LDV. The technology is already quite mature in terms of safety and reliability. However, the main concern for buyers of electric LDV's is the range. Just a few years ago, the range would be restricted to about 60 miles (100 km) in real driving but recent models achieve up to 238 miles (380 km) on one charge in real driving conditions.

Electricity generation is becoming increasingly low carbon. The share of carbon free gross electricity generation (i.e. nuclear and renewable energy forms) in Mexico is on average 22% in 2016 and expected to increase to 41% in 2030 (PRODESEN expectations).

Electric vehicles not only have zero-tailpipe emissions, but they can also make a significant contribution to removing GHG emissions from transport, even when emissions from the power stations are taken into consideration. With the average carbon intensity of the power sector, electric LDVs emit less GHG than their internal combustion equivalents.

Supplying renewables and other low-carbon power to EVs clearly, enforces their climate advantage (according to the GreenEmotion project.[20])

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[20] http://education.greenemotion-project.eu/the-big-picture/climate-impact-of-evs.aspx

The climate impact of BEVs needs to be put into a timeline perspective also. A BEV car sold today will have declining climate impact during its lifetime – which is totally depending on the change in electricity production in the given region or country relying on the decarbonization pace of the power sector. Based on the estimated carbon intensity of the power sector according to the EU reference scenario, by 2035 the average electric vehicle could deliver emissions of about 28 g CO_2/km [(21)]. Electric vehicles have the potential to become nearly zero-carbon in terms of GHG emissions depending on the transition to carbon-free energy sources in the electricity production.

Electric vehicles can contribute to air quality improvement, especially in urban areas since they produce neither NOx emissions nor particles (PM) while running in electric drive mode. PM affect more people than any other pollutants. Short-term effects of particulate air pollution impair especially the respiratory tract, weaken the heart and circulatory system and lead to increased mortality rates.

Well-to-wheel energy efficiency analysis also shows that electric vehicles are more efficient than ICEs[22] over a broader range of primary energy sources.[23]

Battery technology

Traditional lead-acid batteries are not suitable for propulsion of modern road vehicles and shall thus be considered obsolete. They are only used as a low-cost alternative in niche applications such as mobility scooters and forklift stables.

Some early electric cars between year 1990 and 2000 used Nickel-metal hydride batteries, which have up to twice the capacity-to-weight ratio of lead-acid batteries. These batteries have however completely been phased out in favor of the more modern lithium chemistry.

The term “lithium-ion” generally covers chemistries with lithium. Lithium-ion batteries offer 3-6 times the capacity of lead-acid batteries (www.batterividencenter.dk). The most well known chemistry that was first employed in BEVs (such as the Tesla Roadster) is commonly used in laptop computers, electric tools and other power demanding applications. It has a cobalt oxide cathode and a graphite anode. This battery type has a very high power density, but it has a tendency to ignite and burn

[21] Estimated power sector carbon intensity of around 140 g CO2/kWh in 2035, European Commission Trends to 2050

[22] Internal combustion engines

[23] See JEC (2014b) WTW Version 4a

uncontrolled when damaged. It also has a limited lifespan, due to fast degradation and a relatively low number of discharge cycles.

Newer lithium chemistries have been developed (such as the iron-phosphate, titanate and spinels) that are generally safe, but with lower energy densities than the cobalt/graphite variant. These new chemistries are however optimized for long service life with many discharge cycles and in some cases very high charging currents, which allows very rapid recharging. These new generations of batteries removes most uncertainties related to safety, battery degradation and charging duration.

The DC voltage in the BEV is in many cases in excess of 400 volts. To avoid the risk of electric shock, the high voltage system is thus completely isolated from the chassis. This is in contrast to the common 12 volt system used for lighting and other car accessories, which are directly grounded to the chassis. It is also very different from overhead power lines, which are only insulated by air, and can discharge directly to earth.

Electric motor technology

Most moderately priced electric cars have one electric motor connected to either the front or rear wheels. More expensive luxury vehicles from e.g. Tesla and BMW have dual motor configurations, which provide four-wheel drives. Some prototypes have one electric motor integrated in each wheel.

Modern BEVs use DC brushless, AC synchronous or AC asynchronous motors. High power frequency controllers are used to moderate the motor speed and power according to demand. DC motors typically use magnets made from rare earth material, AC synchronous motors use magnetizing coils instead. The AC asynchronous motor uses neither.

The electric motors have excellent characteristics for vehicle propulsion, with maximum torque available from low to medium speed. For the same reason most electric cars have a fixed gearing, which provides both satisfactory acceleration and a top speed limited mainly by the power available from the battery pack. When comparing the power rating from electric cars with the power rating of gasoline or diesel cars, it is worth noting that the fueled engines usually deliver their maximum torque at engine speeds above 2000 RPM. Electric cars with power ratings equal to fossil-fueled cars may therefore have a significantly faster acceleration, which is particularly advantageous in urban traffic. As a rule of thumb one electric kW equals 1½ traditional, engine kW.[24]

Vehicles

Electrification is also being introduced for MDV in the world market (although not yet being introduced in Mexico), buses and small HDV. The MDVs that have until now been introduced to the market are small size MDVs, whereas we have not yet seen larger MDVs with electric engines, because it is not a mature technology yet.

There are some smaller electric trucks or HDV being introduced in the international market today. However, only in very limited numbers. The main problem is to have enough power to run a vehicle and at the same time have enough carrying capacity on the vehicle. Many of the electric vans and trucks are so-called range-extended hybrids, but examples of full electric vehicles are seen. Electric garbage recollection trucks have also been introduced as retrofitted diesel trucks in e.g. the Netherland and Denmark. The electric garbage recollection truck is advantageous due to a lower noise when operating the incinerator. This is considered a benefit in dense urban areas. The costs of trucks and vans are however, still rather high due to the large battery capacity needed.

For buses, electrification is not new. Trolley buses have been used for many years. However, the battery electric buses are newer and are being introduced on urban bus lines. The charging technology is quickly being developed to support also introducing electric vehicles on routes with a longer operating range. Charging can be made at bus stops with pantographs being raised from the vehicle (see Figure 2-12).

Charging infrastructure

A basic fueling infrastructure for electric LDV's already exists in Mexico. All areas where houses have a dedicated parking spot and an electric outlet are suitable candidates for electric LDV's. Charging should not be done directly from the outlet, but from a dedicated charging station, which does a certified electrician install. These are typically about $US 1,000. To fully exploit the potential for electric LDV's also for longer trips however, fast charging networks much be setup by private or public enterprises. These are rather costly, costing $50,000–100,000 per station[25], and

[24] See the Green eMotion project. http://education.greenemotion-project.eu/before-you-decide/performance-and-consumption-metrics/performance.aspx

[25] See the Clean Technical webpage: https://cleantechnica.com/2014/05/03/ev-charging-station-infrastructure-costs/

may not be used very much, because of the obvious convenience of charging at home overnight, instead of waiting at a public charging facility. However, they are necessary to provide range-security for the owners of electric LDV's. This security is needed for people to broadly accept electric cars as a viable alternative to fueled LDV's for especially the longer intercity trips.

Prices

The price of an electric LDV is still much higher than a hybrid LDV (INECC, 2016). In some countries, tax credits or other type of incentives offsets the price difference. The strongest package of incentives for electric cars is found in Norway. These incentives include tax breaks, free charging, free parking, free ferry rides, toll free bridge passage and much more. This has turned Norway into the fastest developing market for electric LDV's. INECC (2016) further estimates that the electric car has a total cost of ownership looking over 15 years to be around 80% higher than a gasoline LDV. The price difference for a hybrid LDV is estimated to be around 40%

Perspective

Electric transportation is now rather developed with several vehicle producers these years introducing BEVs and some PHEVs on the market. The main barrier still with electric vehicles is the operating range. The cars with very long operating ranges are still rather costly. However, the battery technology is also continuously being improved, but there is still room for increasing the performance and cost of batteries.

As the electricity is changing more and more to renewable fuels, the electric vehicles will become one of the cleanest technologies in the market. Hence, this is highly dependent on the changes happening in the power production sector.

Hydrogen

Introduction

FCEVs[26] and hydrogen provide an alternative proposition in the transport sector. Hydrogen is a gas with a calorific value of 142 MJ/kg (higher heating value, HHV). The lower heating value (LHV) is obtained by multiplying with 0.846.

The density of hydrogen at standard temperature and pressure is just 0.09 kg/m^3. Therefore, hydrogen must be compressed or liquefied if it is to be used as an automotive fuel.

The boiling point is -252°C at atmospheric pressure. Advanced cryogenic storage solutions can be used to store hydrogen in this state.

Although hydrogen can be used in combustion engines, it is generally much more efficient to use hydrogen in fuel cell stacks. Hydrogen can also be added to natural gas or biomethane to improve their combustion characteristics.

Production and storage

Similar to electricity, hydrogen is an energy carrier that can be produced from a wide variety of primary energy sources.

The technology for hydrogen production is mature and several alternative production pathways are in place. However, distribution of hydrogen is demanding.

Currently, hydrogen is predominantly produced by steam reforming of methane, via a chemical transformation process generally involving decarbonization of a hydrocarbon. Hydrogen can also be produced from renewable or nuclear energy using electrolysis or biomethane reforming, via organic feedstock and splitting of water (here we will refer to “thermal” hydrogen), which offers zero or close-to zero-emission pathways from well to wheel.

The increase of intermittent renewable energy sources, such as solar and wind energy, in power systems is causing operational challenges, such as grid stability, and has led to calls for a greater use of energy storage amongst other measures. Hydrogen is viewed as one of the key solutions for large scale and long-term energy storage. In order to fulfil this promise several technologies need to be further developed. For example by conversion of electricity to hydrogen, which is already possible via electrolysis.

Large-scale storage of hydrogen is feasible and has been commercially proven in at least one case where hydrogen is stored in an underground salt formation. However, integration with intermittent production of hydrogen has not yet been demonstrated, whilst a suitable business case whereby the location of the storage is dictated by wind/sun patterns and geological conditions has yet to be defined. To exploit the large-scale storage capacity of the Natural Gas (NG) grid, the first demonstrations of blending hydrogen into the natural gas grid are starting right now. These are still small scale and inject at a relatively low-pressure entry point.

The potential for hydrogen as a fuel is significant. Hydrogen can be produced from a variety of primary energy sources. The absolute dominating pathway for production of hydrogen is steam reforming of hydrocarbons, first of all methane. Small amounts are produced through electrolysis of water. Hydrogen is produced in large quantities for industrial applications. The cost of production and energy efficiency can still be improved. In addition, significant investments would be needed in the distribution network for hydrogen, which has been identified as one of the key bottleneck towards adoption of hydrogen as large-scale transportation fuel. The availability of hydrocarbon as such is not seen as a barrier against expansion of hydrogen as a future transport fuel.

One of the perceived merits of hydrogen is again that in principle it can be produced from virtually any primary energy source. Production pathways differ in terms of cost, environmental performance, efficiency and technological maturity. Steam reforming of natural gas is the most common method of hydrogen production today.

Hydrogen is already produced in significant quantities today mostly for industrial and refinery purposes. Oil refineries, in particular, are large hydrogen consumers for hydrodesulphurization of various streams such as gasoil and heavy oil conversion processes. However, for the use of hydrogen in fuel cells the hydrogen has to be purified to a high level, involving removal of impurities that could affect fuel cell performance. Hydrogen is stored in tanks under very high pressure (up to 700 bars).

In the near to medium term fossil fuels (primarily natural gas) are likely to continue to be the least expensive feedstocks for hydrogen production. Given that their conversion still emits carbon into the atmosphere, transition to zero-emission mobility will require moving to cleaner production pathways, which have the potential to virtually eliminate LCA GHG emissions.

For example, production of hydrogen from renewable biomass is a promising mid-term option with very low net carbon emissions. In the longer term, transition to hydrogen from wind energy should enable zero-carbon mobility. While this technology is rapidly improving, high cost of electrolysers and renewable electricity constitute key barriers towards wider uptake.

Fueling and on-board storage

While hydrogen has very high-energy content per kilogram, it is very light in weight (due to its low molecular weight), even when highly compressed or liquefied. It therefore does not have high-energy content per liter of space required to store it.

The ISO/TC 197 secretariat has developed more than 30 standards for safety, fueling and on-board storage of both liquid and pressurized hydrogen, as well as other related technical standards including hydrogen fuel specifications. These can be found in a catalogue at the ISO website.[27]

Composite fuel tanks are built to accommodate hydrogen up to 700 Bar. At this pressure, the density of hydrogen is 42 kg/m^3 and the energy density is therefore 5.9 MJ/L (HHV). The volume and weight required for the pressure tank is however considerable, as is must be built with excessive amounts of reinforcing fiber composite.

Fueling pressurized hydrogen to vehicles requires advanced fueling stations. The fueling station must be able to supply two different pressure levels (350 and 700 Bar). It must also compensate for heat generated in the tank, which must be allowed to dissipate while refueling. When this is done however, refueling is generally uncomplicated for the consumer, and the process can be completed in a matter of less than 10 minutes.

Cryogenic tank solutions are constructed to accommodate hydrogen at temperatures around -250° C. At this temperature, the density of hydrogen is 71 kg/m^3 and the energy density is therefore 10.1 MJ/L (HHV). Tank constructions are advanced and normally involve several layers of heat reflecting shields separated by vacuum, to shield the tank from both convective and conductive heating. Cryogenic tanks are therefore expensive components, which add to the price of an already expensive vehicle technology.

Fueling cryogenic hydrogen is not much different for the consumer, than fueling the pressurized hydrogen. A standardized nozzle is connected to the vehicle, which ensures that the liquid hydrogen is transferred to the vehicle with minimized evaporation and safely, by returning evaporated hydrogen gas to the station. Fueling a vehicle should be possible in less than 10 minutes.

It still needs significant efforts to set up the necessary hydrogen refueling station infrastructure. However, it does not require a change in user habits in terms of mobility and refueling, and it offers substantial benefits in terms of environmental and energy sustainability.

Motor technology

Vehicles for hydrogen use primarily fuel cell technology, in which the hydrogen combines with atmospheric oxygen by means of proton exchange membrane to form water. The process creates electricity, which is used to power one or more electric motors in the vehicles drive train.

[27] https://www.iso.org/committee/54560/x/catalogue/

Fast load changes on the electric motor(s) are normally handled by batteries, which can deliver extra power when needed and store energy from both fuel cell stacks and regenerative braking. This allows start-up time for the fuel cell stack and an optimized steady load on the system.

The propulsion systems in FCEV are generally much more effective than combustion engine based propulsion systems, and hence the vehicles can typically drive more than 100 km per kg of hydrogen.

Vehicles commercially available

Many concept vehicles have been proposed and displayed on motor shows worldwide. Some have entered small-scale production for limited markets. A few FCEV are available today.

Prices

Different hydrogen production methods like hydrolysis show a wide range of costs between 38 $MX and 206 $MX/kg H2.

The vehicle models in production have driving ranges of 426-589 km. The consumption figures for the models in the market now are equivalent to approximately 66 MPG (gasoline), while the larger vehicles have a 50 MPG equivalent consumption.

The technology is still young and the costs of fuel cell hydrogen vehicles are still much higher than conventional vehicles. It is therefore also very difficult to give real estimates of prices when vehicles are introduced to a mass market.

Perspective

Europe is still considered a technology leader in certain FCH application-areas but other regions (e.g. Japan and the US) are developing quickly as a result of public intervention and support. Impressive technological progress has been made by European companies, especially in the transport sector, also due to good support from projects developed jointly under the European R&D framework program. The public and private sectors came together to form the first Fuel Cell and Hydrogen Joint Undertaking (FCH JU) in 2008 to promote coordination and collaboration across Europe’s FCH sector and accelerate the commercialization of FCH technologies. This initiative has been extended under Horizon 2020 as FCH 2 JU.

Additional to a reliable source for Hydrogen supply, two things are needed for the market introduction of FCEV: the cars themselves and hydrogen refueling stations to support them. In any market, a minimum number of each is necessary to support demand for the other (FuelCelltoday, 2013).

Initial deployments are likely to focus on government fleets, other return-to-base fleet operations and the high-end consumer car market in areas with an appropriate level of infrastructure. Following early market introduction, widespread consumer acceptance and adoption will be gradually, accelerating as infrastructure density increases and the cost of production of the vehicles and the hydrogen fuel decreases. Ultimately, take-up will depend on the advantages and costs of FCEV when judged against alternatives (FuelCelltoday, 2013).

4. Data sheets

The main element of the technology catalogue is the data sheets. The data sheets represent a set of vehicle technologies within four groups of vehicles: light duty vehicles (LDV), medium duty vehicles (MDV), heavy-duty vehicles (HDV) and buses. Within each of these types of vehicle categories, different representative variants are included. The typical categories are three 'size' categories and one or more categories representing future or low carbon technologies.

Each vehicle type included in the data sheets are representing a group or class of vehicles. The parameters included in the data sheets therefore show the most common value of vehicles contained within the category. This means that the data does not correspond to one particular vehicle, but are the values that which is most typical for this technology.

The data presented are too a very large extent based on Mexican data sources and complemented by international values and sources, where these are considered more reliable and when Mexican data has not been identified. The ambition has been to ensure the highest level of generality and reliability of the data.

Elements of the data sheets

For each technology the data sheet will show the following data for the years 2017 (the current situation), 2020, 2030. Data for 2020 and 2030 are to be considered as what are the expected values for a new vehicle purchased in this particular year. The projections into future years are obviously uncertain. The projections are therefore based on international sources, which indicated the relative changes in energy consumption and emission patterns (e.g. from the IEA). These relative changes are used to project the current vehicle characteristics.

Technical parameters

- Type of fuel (diesel, CNG, gasoline, electricity or other)
- Energy consumption (MJ fuel per km)
- Energy use (Km/L, kwh/km and similar)
- Availability (is the car on the Mexican market)
- Technical lifetime (years)
- Annual range in km per charge/fueling for alternative fuel technologies

Environment

- Certification (is it certified by PROFEPA, if not what are emissions)

- CO_2 (g per km)
- Particles (g per km)
- Black carbon (g per km)
- SO_X (g per km)
- NO_X (g per km)
- CH_4 (g per km)
- N_2O (g per km)

Investment and operations cost parameters

- Price (price on the Mexican market including VAT)
- Maintenance costs (annualized cost of maintenance including VAT)
- Insurance costs
- Fuel costs

The cost figures are calculated using a set of basic parameters covering:

- Fuel prices per liter, kwh or Nm^3 (Source: Mexican official price lists)
- Price inflation factors based on the % annual increase in prices (Source: Economic Prospective of Mexico by SHCP for 2017-2022, assuming same inflation until 2030)
- Insurance as a factor of investment costs (Source: INECC, 2016)
- Maintenance as a share of investments costs (Source: INECC, 2016)
- Purchase costs (investment costs) (Source: a wide selection of producers home pages, average values used)

The costs are then calculated as a per kilometer cost using the above main inputs

Main sources used in the data sheets

There are several data sources available for the environmental impact of vehicles. The main data source has been the Ecovehiculos database on almost all versions of vehicles registered in Mexico. This is complemented by databases and models developed by the EPA in USA for which specific Mexican data largely is taken into account (e.g. the AFLEET tool and the MOVES model with a special application for Mexico, and data). The EPA sources build on the vehicle fleet compositions in to find the right 'average' values. Car fleets in Mexico and USA differ from European cars in the following respects:

- Cars and engines are generally smaller in Europe
- Most cars in Europe have manual transmissions
- Half the cars in Europe are diesels
- Gasoline trucks and vans are very rarely used in Europe

Due to the circumstances mentioned above we have chosen three main data sources. They are the Mexican database Ecovehiculos covering all models of LDV and MDV introduced to the Mexican market, and the international AFLEET model, and the MOVES model database, which is based on the US EPA registrations of energy and environmental performance of vehicles. The tool combines the actual performance of individual vehicles with the actual fleet and use composition in Mexico (or any other country of interest).

ECOVEHICULOS

The Energy Efficiency and Vehicle Emissions Portal (EcoVehículos) developed by INECC, collects and publishes clear and timely information regarding emissions, performance and annual fuel expenses of new and semi-new light vehicles available in the domestic market. The technical characteristics of the vehicles are summarized in two grades that combine the attributes of performance and emissions, in order to provide information to car consumers to make informed decisions that impact their economy and in favor of the environment. In addition, it seeks to encourage the automotive industry to produce more efficient and cleaner technologies and to link consumption decisions with costs and benefits to society.

The fuel consumption and pollutant emissions data reported in the Ecovehículos Portal are obtained from the tests carried out by the manufacturers under controlled laboratory conditions and are provided only for unofficial comparative purposes.

AFLEET Tool

The AFLEET Tool 2016 is a module of the GREET1_2015 software produced by Argonne National Lab at Chicago University. GREET is a very comprehensive model of vehicle life cycle emissions. Argonne has developed the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool for Clean Cities stakeholders to estimate petroleum use, greenhouse gas emissions, air pollutant emissions, and cost of ownership of light-duty and heavy-duty vehicles using simple spreadsheet inputs.

The tool uses data from Argonne's Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) fuel-cycle model to generate necessary well-to-wheels petroleum use and GHG emission coefficients for key fuel production pathways and vehicle types.

In addition, EPAs MOVES-MX model and certification data are used to estimate tailpipe air pollutant emissions. Various sources are used to provide default cost data, including the Clean Cities Alternative Fuel Price Report and American Recovery and Reinvestment Act awards. The software is license free.

In the datasheets, the AFLEET tool is primarily used to establish Tank-to-wheel fuel economy factors and cost estimates for the different vehicle types.

MOVES emission factors in GREET:

The latest update from 2014 aims to update the GREET vehicle model year (MY)-based emission factors of various air pollutants from vehicle operation activities involving various vehicle technologies, using the EPA's MOVES-MX model (EPA, 2014a).

In the datasheets, the MOVES model is primarily used to establish pollutant emission factors such as NOx, CH4 and Particulate matter.

Other emission factors are linked to energy consumption, by using the quantity of emissions per MJ of energy consumed.

Technologies covered

The datasheets include as mentioned both current conventional (baseline) technologies and low carbon technologies.

Baseline technologies

- Standard gasoline car (LDV baseline):
    - High technology, low emission sub-compact
    - Sub-compact
    - Compact
    - SUV
- Pick-ups
    - Small pick-up, gasoline
    - Medium pick-up, gasoline
    - Diesel pick-up and van
- Diesel trucks (HDV baseline)
    - Small truck (Class 2b to 5, vocational truck)
    - Medium Truck (Class 6 and 7; one vocational and one tractor-trailer)
    - Large truck (Class 8; one vocational and one tractor-trailer)
- Diesel buses (HDV baseline)
    - Small buses (Class 5-6, city bus)
    - Medium buses (Class 7, Urban and interurban line buses – two variations)

- Large buses (Class 8, Interurban line buses and coaches – two variations)

We note that the baseline vehicles represent the technologies that are introduced in the Mexican market already. Hence, they correspond to the technology in the vehicles that can be bought and used in 2017. This means that they comply with current energy and emissions standards such as Euro V and EPA 2010 standards.

The HDV vehicle classes and the definition of the Class 2b to 8 is outlined in the table below (from EPA, 2015) and is the same categorization proposed for México:

Regulatory Class Description	regClassName	regClassID	Gross Vehicle Weight Rating (GVWR) [lb]	Source Types (SourceTypeID)	Operating Mode Basis[2]
Light-heavy duty ≤ 10,000 lbs. (Class 2b Trucks with 2 Axles and 4 Tires.)	LHD≤ 10K	40	8,501 – 10,000	Passenger Trucks,(31) Light Commercial Trucks(32)	VSP
Light-heavy duty ≤ 14,000 lb. Class 2b (Trucks with 2 Axles and at least 6 Tires or Class 3 Trucks.)	LHD≤14K	41	8,501 – 14,000	Buses (41, 43), and Single Unit Trucks (51,52,53,54)	STP
Light-heavy duty 4-5	LHD45	42	14,001 – 19,500	Buses (41, 42, 43) and Single Unit Trucks (51,52,53,54)	STP
Medium-heavy duty	MHD	46	19,501 – 33,000	Buses (41,42,43), Single Unit Trucks (51,52,53,54), and Combination Trucks (61,62)	STP
Heavy-heavy duty	HHD	47	> 33,000	Buses (41,42,43), Single Unit Trucks (51,52,53,54), and Combination Trucks (61,62)	STP
Urban Bus	Urban Bus[1]	48	> 33,000	Transit Bus (42)	STP
[1] see CFR § 86.091(2).					
[2] MOVES assigns operating modes based on VSP or STP, depending on source type					

The classes can be described as:

Light Duty Trucks

The light duty trucks comprise of commercial truck classes 1, 2 and 3. The class is determined by the GVWR of the vehicle.

- Class 1 – This class of truck has a GVWR of 0 to 2,722 kg (0 to 6,000 pounds).

- Class 2 – This class of truck has a GVWR of 2,722 to 4,536 kg (6,001 to 10,000 pounds).
- Class 3 – This class of truck has a GVWR of 4,536 to 6,350 kg (10,001 to 14,000 pounds).

Medium Duty Trucks

The medium duty trucks comprise of commercial truck classes 4, 5 and 6. The class is determined by the GVWR of the vehicle.

- Class 4 – This class of truck has a GVWR of 6,351 to 7,257 kg (14,001 to 16,000 pounds).

- Class 5 – This class of truck has a GVWR of 7,258 to 8,845 kg (16,001 to 19,500 pounds).
- Class 6 – This class of truck has a GVWR of 8,846 to 11,793 kg (19,501 to 26,000 pounds).

Heavy Duty Trucks

The heavy duty trucks comprise of commercial truck classes 7 and 8. The class is determined by the GVWR of the vehicle.

Class 7 and 8 vehicles require that the driver has a Class B CDL to operate the vehicle.

- Class 7 – This class of truck has a GVWR of 11,794 to 14,969 kg (26,001 to 33,000 pounds).
- Class 8 – This class of truck has a GVWR of greater than 14,969 kg (33,001 pounds), and includes all tractor trailers.

For the projections into the future years, the vehicles generally comply with the Euro VI standards. However, the data presented are based on the expected average performance of the future vehicles.

For the diesel technologies presented, it is acknowledged that there is uncertainty as to when low Sulphur diesel (see the discussion of fuel quality in this document) is widely required and introduced in Mexico. Hence, the data sheets also include a *High Sulphur Diesel* alternative projection.

Low carbon technologies:

The different low carbon technologies include both alternative fuels and conventional fuels with Hybrid technology. Biofuels are not considered since, as outlined in this document, they are mainly used as blend-in in conventional fuels and do not change the emission or energy of the vehicle tank-to Wheel patterns.

- Hybrid gasoline-electric (LDV)
- Plug-in hybrid electric (LDV)
- Electric (LDV, MDV and buses)
- CNG (HDV and buses)
- Hydrogen-fuel cell (LDV)

Generally, a number of biofuels can also be used. However, these do typically not require new types of vehicles technologies, since the biofuels are blend in as conventional fuels. There are some restrictions on the quality of the biofuel to make it available. Moreover, in higher blends, specific engine technologies are required (such as the ethanol or E-85 vehicle technology).

Base assumptions and calculations

SO_2:

For gasoline, we use a baseline Sulphur content of 30ppm.

$$\frac{30\ mgS/kg\ fuel}{43\ MJ/kg\ fuel} \cdot \frac{64.066}{32.065} mgSO_2/mgS = 1.39\ mgSO_2/MJ$$

For diesel, we use a baseline Sulphur content of 500ppm.

$$\frac{500\ mgS/kg\ fuel}{42.7\ MJ/kg\ fuel} \cdot \frac{64.066}{32.065} mgSO_2/mgS = 23.40\ mgSO_2/MJ$$

Energy consumption:

All energy is based on LVH (Lower Heating Value) also known as Net Calorific Value.

The following relations are taken from the AFLEET TOOL can be used to estimate the energy consumption of an alternative fuel vehicle when there is no other data available. These relations are internationally recognized (and in Mexico) as reliable. Hence, in developing energy consumption for vehicles, where there is not many vehicles to observe, and these relations are used to establish the energy consumption in the data sheets. The factors are based on similar vehicle size and weight. They should be used if an alternative fuel vehicle is not available in the exact same size and weight as the reference vehicle.

- Gasoline = Ethanol [MJ/km]
- Gasoline = 0.95 * CNG [MJ/km]
- Gasoline = 1.20 * Diesel [MJ/km]
- Gasoline = 1.40 * Hybrid [MJ/km]
- Gasoline = 1.49 * PHEV [MJ/km]
- Gasoline = 1.99 * Hydrogen [MJ/km]
- Gasoline = 3.30 * Electric [MJ/km]
- Diesel = Bio diesel [MJ/km]
- Diesel = 0.85 * CNG [MJ/km]
- Diesel = 1.65 * Hydrogen [MJ/km]
- Diesel = 2.75 * Electric [MJ/km]
- Diesel dual fuel LNG = 0.95 * CNG [MJ/km]

CO_2:

CO_2 emissions are calculated on a tailpipe basis, according to the EU Concawe Tank-to-Wheel report. Emissions from fuel production and distribution is not included.

- Gasoline 73.4 g/MJ
- Diesel 73.2 g/MJ
- CNG 56.2 g/MJ
- LNG 56.2 g/MJ
- Bio diesel 0 g/MJ
- Electricity 0 g/MJ
- Hydrogen 0 g/MJ

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