



Future Light and Heavy Duty ICE Powertrain Technologies

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ERTRAC Working Group Energy and Environment



1 Introduction

Personal mobility and transportation of goods are fundamental needs of modern society. Any approach to fulfilling these needs must meet sustainability criteria in addition to achieving customer acceptance. Accordingly solutions and services have to comply with safety, energy efficiency. Security and environmental requirements as well as affordability.

To fulfil these criteria, the transportation system needs to evolve with improvements in and changes to the powertrain and vehicle technologies in combination with improved fuels and energy sources. The need to increase energy security and to reduce the dependency on fossil and crude oil based fuels will drive towards a wider use of renewable energy sources.

Long term trends related to the evolution of personal mobility needs, but also in relationship to goods transportation, will contribute to shaping of the market portfolio. More people are expected to live in large agglomerations and they will continue to ask for “clean” and efficient solutions. These will be provided not only by vehicle technological advancements but also by the optimisation of their use thanks to the increasing role of connectivity. Likewise the long haul transportation system will benefit both from connectivity that will enhance automated driving conditions especially on intercity and highway routes, and from a wider penetration of intermodal model schemes .

Based on long-term planning information from industrial partners ERTRAC’s Strategic Research Agenda predicts that 60% or more of the new passenger vehicles in Europe will still be powered with an Internal Combustion Engine (ICE) even in the long term horizon out until 2040: Powertrain applications will include ICE, Hybrids, Range Extender architectures as well as dedicated alternative fuels (e.g. natural gas) engines. Similarly the heavy duty market is expected to be dominated by ICE for some time, due to the need for energy density in propulsion of larger vehicles.

ERTRAC’s Research Strategy advocates a systems approach where several pillars contribute to a low-carbon and pollutant poor economy.

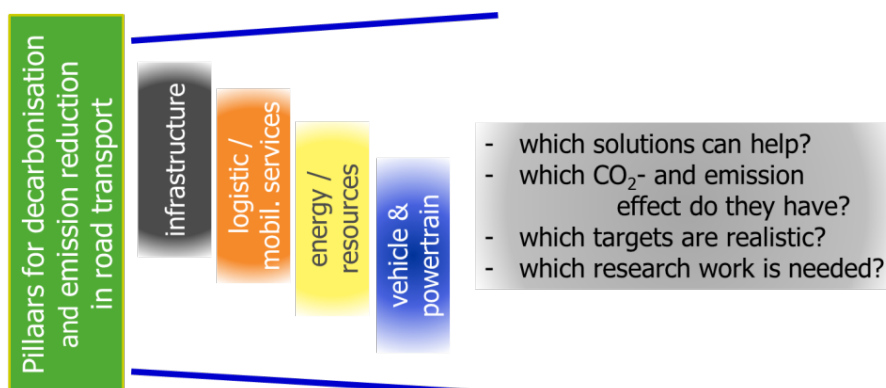


Figure 1.1 ERTRAC systems approach with pillars for decarbonisation and emission reduction

This roadmap concentrates on the powertrain technologies for both light and heavy duty vehicles which are needed for propulsion as well as the energy sources that are available to these powertrains.

The role of the EU collaborative research

In particular, for mature technologies like the ICE, the further improvement opportunities must be discussed comprehensively. This is crucial to follow the right development paths and to achieve the possible advances in conventional powertrain technologies. The European Framework Programmes offer the only opportunity for comprehensive collaborative research in integrated projects, with agreed targets and RTD agendas ranging from joint requirement analysis to the assessment of results.

Actually this goes beyond the technical RTD and engineering projects. In general, the road mapping activities like this report would not be possible without the contributions from leading researchers from all relevant stakeholder groups. For research topics which are still in a pre-competitive TRL level this is well-established between OEMs, supply industry and research providers. In addition, the European Framework Programmes are the only programme worldwide where any kind of international collaboration is possible, which is important when facing global challenges like greenhouse gas reduction, for global research themes like fuels and engines.

2 EU road transportation scenario

The EU Climate and Energy Framework is the basis for emissions reduction in all sectors including transportation in Europe. The framework states an objective of reducing GHG emissions in the EU from all sectors by 80 to 95% by 2050 compared with 1990 levels. This target also sets out boundaries for the transportation sector which is further defined in the Transport White Paper which was issued in 2011. The latter document states the objective to reduce the GHG emissions from the transport sector by 60% by 2050 compared to 1990 and by 20% by 2030 compared to 2008 levels. In 2014 targets for 2030 were announced as follows:

- **At least 40% cuts in GHG emissions (from 1990 levels).**
- **At least 27% share for renewable energy.**
- **At least 27% improvement in energy efficiency.**

2.1 ERTRAC's Perspective

Within the vehicle category there are contributions not only from the propulsion and energy side but also from other aspects related to the vehicle body rather than the powertrain so aerodynamics, weight, size, friction, tyres etc.

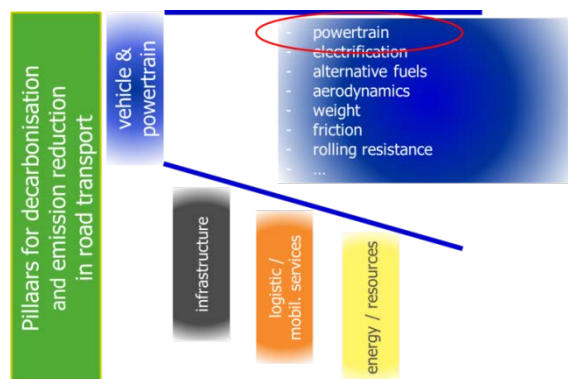


Figure 2.1 ERTRAC's system perspective

Within the evolution of the transportation sector the expectation is that fossil-based fuels will dominate the energy pool for road transport till 2030, and even on the longer time horizon (2040), the road transport energy supply mix will be composed of four main sectors: oil based fuels, natural gas, renewable liquid fuels and electricity, itself mostly produced from renewables. While electrification will progressively penetrate the powertrain sector, conventional fuels, power to liquid and gaseous fuels (PtX), and advanced biofuels together with an increasing amount of natural gas will play a major role in combination with Internal Combustion Engine technologies. Most of all scenarios until 2040/2050 investigated and discussed consider regulations of CO₂ fleet emissions which do not include mandatory zero-emission vehicles in particular areas. Hence, various types of powertrains using liquid or gaseous carbon-based fuels (incl. bio-mass based and PtX) – due to their inherent advantages regarding energy density, availability and very high convenience and comfort for the user – would still cover up to 80% of the fleet (even if the major part of these powertrains will certainly be hybridised and/or partly electrified) in 2040 (see Figure 2.2).

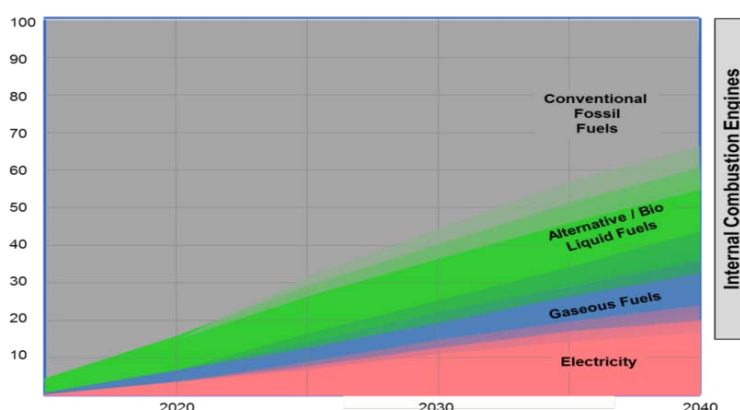


Figure 2.2 The evolution of passenger road transport energy towards 2040

Under this scenario, powertrain development has to aim at taking a sustainable approach to both ICE based powertrains and clean, alternative energy carriers for mobility given that powertrains involving certain types of ICE will be the major contributor to the transportation sector. In parallel, political measures taken to comply with air quality legislation for selective cities could lead to acceleration towards “clean” powertrains based on electric propulsion or

alternative fuels and a consequent limitation in the use of conventional ICEs. The evolution of the ICE based powertrains can be described by the following two-step pathway:

- Development of new combustion-based propulsion technologies (gasoline, diesel, PtX, advanced biofuel blends and ICE with fossil and renewable gaseous fuels) in order to achieve optimal performance on a Well-to-Wheel basis and to ensure both energy security and GHG emission mitigation.
- Additional decarbonisation will then occur through the uptake of electrically-powered drivetrains (battery electric vehicles (BEV) and hybrids (HEV)) and the development of new ICE concepts to complement in synergistically complements the electric drive. However, development of suitable vehicle on-board storage technologies to provide energy density for the electricity and a suitable infrastructure for e-charging still present challenges.

For heavy duty vehicles the accompanying plug-in electrification is expected to be less used with light duty transport and the main CO₂ reduction must be gained through powertrain efficiency improvement and/or a wider use of alternative/bio fuels.

In cities and conurbations fully electric city vehicles and hybrids will dominate in the future, since range anxiety related to limited battery capacity and long charging times is less crucial for city driving. Despite urbanisation, vehicles driving in non-city environments can be expected to remain the bigger share of the total.

At the same time the decarbonisation process will be sustained by the progressive uptake of low carbon fuels, such as advanced biofuels and PtX allowing an effective and consistent use of renewable/waste energy sources and of natural gas with a lower carbon footprint. It should be noted that even the potential of advanced biofuels will be limited due to limited resources such as arable land and water.

In this scenario, there is a chance of a role for fuel-cell vehicles in the transportation sector, but this will still be affected by uncertainties due to high system costs, currently a poor hydrogen distribution grid and infrastructure and the lack of renewably produced hydrogen. Of course hydrogen can be produced locally and stored dependent on the temporary availability of renewable sources. If successful, fuel-cell vehicles could change the future powertrain scenario fundamentally; nevertheless this seems to be a longer term scenario. On the other hand it is expected that within the next years the necessary technical progress will be made in battery technology and development of grid/recharging stations to support an effective market penetration of electrified vehicles.

With this perspective vehicles with ultra-efficient Internal Combustion Engines – particularly developed for use of low-carbon fuels such as gas - will still play a dominant role in mobility to 2030, retaining a major role until 2040 and beyond.

2.2 The European industry and market perspective

European OEMs and suppliers are world leaders in ICE technology; maintaining this lead is essential therefore to support export opportunities in a growing global automotive market,

with the EU automobile exports currently running at over 120 bn € annually. Moreover, the non-OECD market is expected to triple between 2010 and 2035 according to IEA.

From one side there is, therefore, a need to continue development of battery technologies especially for urban mobility whilst, on the other hand, ICE and electric powertrains will coexist for low and mid vehicle ranges. Without any doubt long range journeys will still be based on ICE technologies, for passenger cars and especially for heavy duty truck applications.

A specific pathway to a significant increase in powertrain efficiency lies in an unbiased reallocation of powertrain functions and redesign of powertrain architecture. Such a reallocation will utilise the specific advantages of each type of propulsion engine and consequently avoid respective weaknesses. High dynamics are more difficult to realise with an ICE whereas an electrical motor easily provides almost instant torque. Constant full power and long range are challenging for the electrical drive but strong features of the ICE. The redesign requires novel transmissions and breaks with “off the shelf” recombination of existing modules from non-hybrid powertrains into a hybrid powertrain. On the hand it offers the chance to provide full powertrain functionality at reduced complexity and cost. The latter being of paramount importance for customer acceptance and fast market penetration of electrified powertrains. All these scenarios expect a further diversification in powertrain technologies. Power for on-road vehicles will be provided by powertrains including combinations of:

- Ultra-efficient Internal Combustion Engines (ICE) with dedicated Spark and Compression Ignition (SI & CI) combustion systems for particular fuels and application profiles.
- Electric propulsion systems.
- Various forms of hybridisation, from mild- to full-hybrid, mainly targeting PHEV (Plug-in Hybrid Electric Vehicle).
- Liquid fuels for SI and CI ICE (diesel, gasoline, blends and advanced liquid biofuels).
- Gaseous fuels (CNG/LNG, H₂) for ICE and fuel cells, including different bio-methane paths and power-to-gas.
- Electricity provided on board by batteries and, with a long term perspective, fuel cells.

For increasing ICE thermal efficiency, reducing heat and friction losses to recover and save energy still represent important areas of research. The role of advanced materials should also not be underestimated. The evolution towards electrified powertrains will also enable new functionalities and opportunities for optimisation of the energy balance of the powertrain.

To enable a balanced approach, it is necessary to consider the entire energy and carbon footprint of the solutions, including the upstream contribution related to the fuel production and distribution. With the limited potential of biofuels, the development of technologies for Power-to-Gas and Power-to-Liquid is inevitable. The usage of Power-to-Liquid as drop-in fuels not only for aviation and shipping but also for road vehicles offers the benefit of reducing CO₂ emissions even for the existing vehicle fleet and of limiting additional costs that are associated with Power-to-Liquid in comparison to fossil fuels.

To support these long term goals, it is fundamental that a common vision is shared at the policy level to develop the so called “integrated” approach. This enables the conditions where new technologies can penetrate the market, providing the expected benefits in terms of environmental preservation, of personnel mobility and goods transportation as well as maintaining EU industry competitiveness.

Generally it is clear that new powertrain solutions will find the right conditions to penetrate the market only if an integrated approach is ensured at the political level, creating the appropriate political environment, supporting future R&D as well as safety and security, generating the fuel/energy distribution infrastructures, leveraging the progressive fleet renewal conditions and supporting customer acceptance through education.

3 Challenges and technology potentials for ICE based powertrains

ICE technologies will play a major role for the next decades mainly due to the energy and power density capability provided by liquid and gaseous fuels and the widespread existing infrastructure: The energy density of chemical energy storage in hydrocarbon based fuels will always be greater than electro-chemical storage (current difference: two orders of magnitude). Based on the same package the range of chemical storage is significantly higher than that of electro-chemical storage. Also from the recharging time standpoint liquid and gaseous fuels still offer the best performance and flexibility in use.

To fulfil future environmental, societal and customer requirements the transport sector is facing two challenges:

1. Facilitating the European Energy Union’s transition to an energy-efficient and low-carbon economy by **increasing the overall efficiency**
2. To further reduce the formation of pollutants (e.g. nitrogen-oxides and particle emissions) in order to **improve air quality** in cities and conurbations.

Comparing the current state of the art of ICE technology with physical limits and including technical options via electrification suggests potential for significant improvement. A detailed analysis and breakdown of the inefficiencies of a modern gasoline and Diesel combustion engines for passenger cars and commercial vehicles is sketched in Figure 3.1.

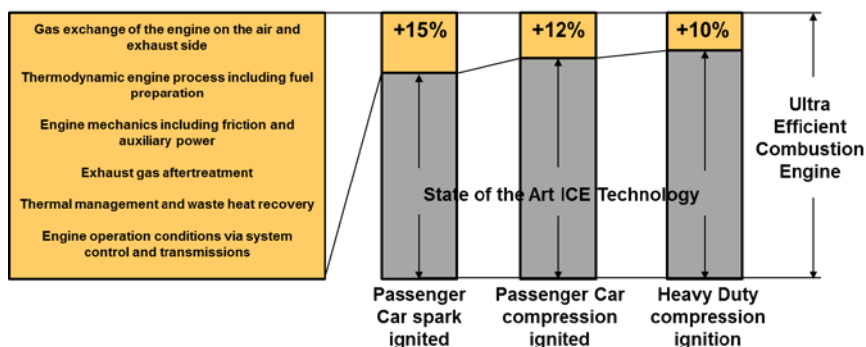


Figure 3.1 ICE efficiency improvements potential

To realise these potentials, further research needs can be summarised under four technology areas, with an emphasis on affordability for all new developments:

- **Further development of components and systems, based on existing engine technologies and application of advanced materials.**
- **New combustion processes and new engine concepts, new combustion sensing methodology & control.**
- **A radical approach to highly efficient, dedicated and robust combustion engines for the usage of alternative/ low carbon and high knock resistant fuels.**
- **The development of dedicated ICEs for electrified powertrains.**

3.1 Light Duty ICE

Vision for the future of internal combustion engines

High efficient and ultra clean internal combustion engine that uses renewable low carbon fuel as key element of an electrified powertrain.

Looking back into the history of combustion engines it becomes obvious that the development was primarily determined by continuous improvements instead of step changing, revolutionary breakthrough technologies. The introduction of direct fuel injection in combination with turbo charging was one of the rare and visible exceptions to this trend.

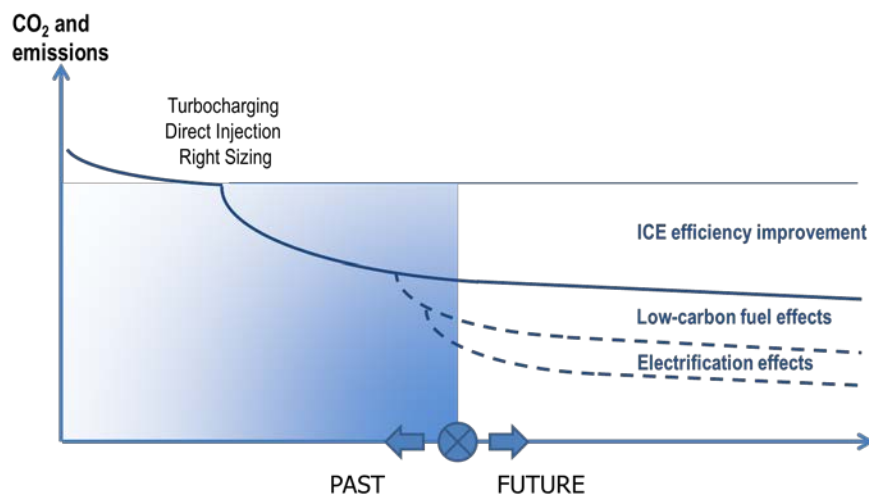


Figure 3.2 Trend of CO₂ emissions caused by Internal Combustion Engines (ICE) along with accompanying measures of low-carbon fuels and electrification of powertrains for on road vehicles

The progress towards optimisation of the powertrain and the internal combustion engine system can be divided into three steps:

1. improvement of the engine efficiency itself,
2. the use of low carbon/near net zero carbon fuels as well as
3. electrification including hybridisation

Increase of overall thermal efficiency

In the future it is of major importance for the ICE to increase the thermal efficiency in the entire engine operating range. Figure 3.2 shows the main contributions to the energy efficiency increase according to the different operating conditions and, on the right side, a list of potential technological approaches.

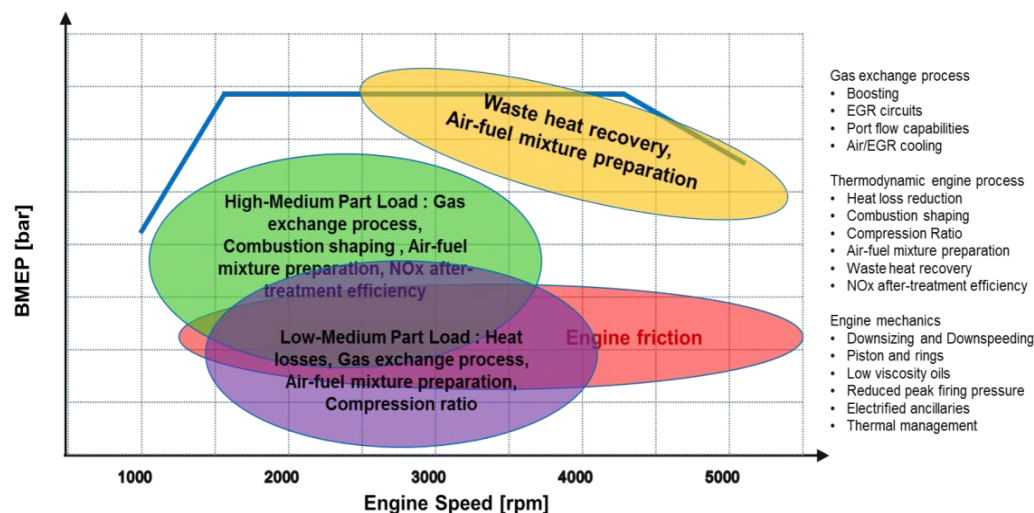


Figure 3.2 ICE improvement areas towards higher energy efficiency

Friction reduction and throttling losses at part load conditions consistently affect spark ignited engines: this could be addressed by the combination of advanced systems for valve-train distribution control (leading also to a cylinder deactivation approach) and the implementation of technological solutions for surface coatings and use of low viscosity lubricants.

Efficiency increases at medium-high engine load will require an extended use of unconventional thermodynamic cycles (Atkinson/Miller) in combination with Variable Compression Ratio (VCR) and advanced valve-train systems and charge dilution to mitigate also at higher load knocking phenomena thus avoiding the need for over-fuelling of the air/fuel mixture.

With regard to passenger car applications, the brake thermal efficiency baseline for gasoline engines is about 38% and for diesel engines is about 42% (peak values).

Current and short term developments aim to increase, as a first step, the gasoline engine efficiency targeting that of the diesel engine, but the long term goal to reach a brake thermal efficiency up to the approx. 50%, needed to contribute to the energy saving and CO₂ emissions reduction targets will also require the progressive optimisation of the ICE waste energy and the introduction of more radical new technologies and combustion approaches. This process is supported in parallel with the development of the electrification/hybridisation technologies.

Improving ICE thermal efficiency is also consistent with targets in other parts of the world. For example Figure 3.3 shows Japan's brake thermal efficiency targets of 50%. In the US the SuperTruck programme is targeting a goal of 55% thermal efficiency (Figure 3.4).

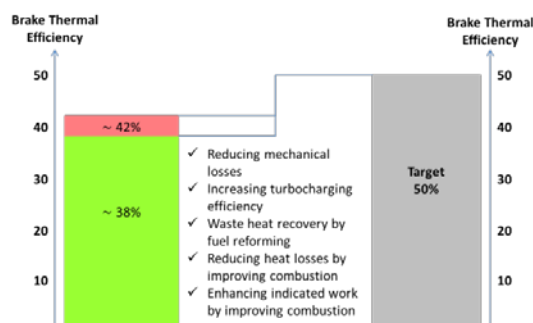


Figure 3.3 Japan's R&D programme on Internal Combustion Engines

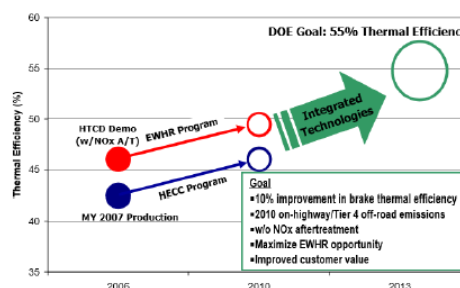


Figure 3.4 US SuperTruck Programme

In general the European Commission and ERTRAC targets are similar and consistent with global strategies for meeting GHG reduction targets.

A 50% peak thermal efficiency means a fuel consumption of 172 g/kWh, today's gasoline brake thermal efficiency of 38% is equivalent to 226 g/kWh, and for diesel of 42% is 205 g/kWh. From today's view and today's knowledge a 50% brake thermal efficiency can be reached only with radically different ICE technologies. To achieve even higher efficiency, it is necessary to have electrification of the powertrain i.e. for hybridisation. Only with the whole system i.e. with an electrified ICE powertrain (ICE + Electric support) can higher efficiencies be realised.

Figure 3.5 shows the reality of CO₂ emissions in the NEDC test cycle related to the efficiency for a mid-class vehicle of 1360 kg.

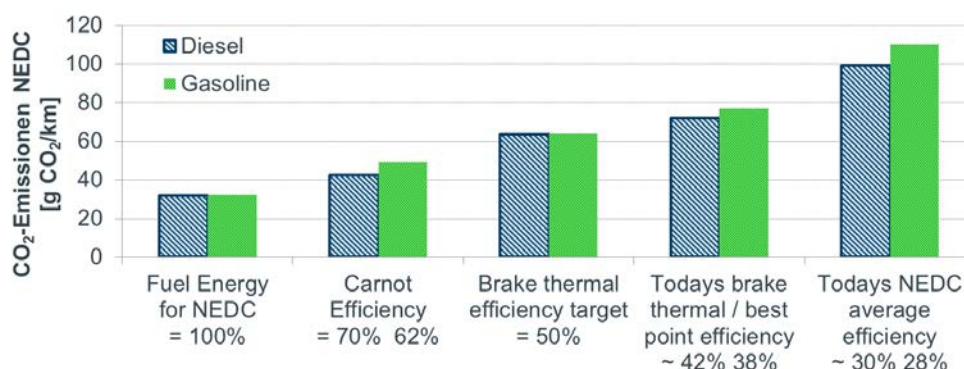


Figure 3.5 Realities of Efficiency and CO₂ in NEDC

These developments will progressively extend the most efficient areas of the powertrain to wider operating conditions closing the current gap between the homologation testing conditions and the real driving conditions.

Nevertheless specific values for real driving fuel consumption are very difficult to predict because of very different driver behaviours and vehicle classes. There is a large variation in vehicles with regard to weight, power, acceleration, etc. and the gap becomes wider the more technologies are incorporated.

For hybrids the gap becomes even larger because fuel consumption is a function of battery size and the portion of electric travel and travel with pure ICE as well as the potential to optimise regenerative braking. It is even wider in the case of a PHEV with extreme range because then fuel consumption becomes a function of only battery size.

All improvements in the ICE technology will have a significant beneficial impact on fuel consumption, on CO₂ output and on emissions reduction, with a wider use of low-carbon fuels (such as Natural Gas) and renewable fuels (advanced liquid biofuels, PtX and different paths for bio and synthetic methane), over a long period of time.

Further steps

The next and potentially last radical step towards a clean, high efficient and ultralow CO₂ emitting powertrain will be based on the usage of low carbon fuels. A very attractive scenario could be based on an optimized engine, dedicated to the combustion of natural gas. This would lead to another 20 – 25 % reduction of CO₂, just by using the favorable chemical composition of natural gas with the lower carbon content. Furthermore the very beneficial combustion behavior can be used towards an efficiency increase of the engine. The final step in this scenario is the partial or complete substitution of the fossil gas by synthetic, sustainable methane. There are similar scenarios using alternative low carbon fuels like dimethyl-ether. All of these concepts reuse CO₂ in combination with hydrogen, generated using sustainable electricity, following the overarching idea of CO₂ recycling.

The electrification of the powertrain will be the predictable, next large step in the direction of efficiency improvement. In this concept the combustion engine will continue to be the dominant energy source for propulsion. The electrified subsystem will recover the kinetic energy of the vehicle and provide this energy directly or indirectly via the combustion engine to the driveline. The consistent use of the recovered electrical energy will lead to an additional, step changing benefit of up to 20%. The overall achievable benefit will depend on the electrification concept and the vehicle application. Without external energy the amount of recovered electricity is limited by the kinetic energy of the vehicle as well as the power of the electric motor which is in turn also its recuperation power limit.

These three steps, high efficiency combustion engine, usage of recovered electricity from kinetic energy and migration to renewable, low carbon fuel are the building blocks for the clean and sustainable propulsion strategy for the future.

Air Quality Enhancement

For the reduction of emissions different technologies are conceptually available and individually demonstrated on the internal combustion engine side as well as for the after-treatment system.

The optimum solution will need to consist of a “systems” approach, as both technical aspects as well as cost aspects are part of the same solution. Development of high efficiency ICE results in a mean increase of peak temperatures inside the combustion chamber, leading to higher NO_x formation. On the other hand, high efficiency ICEs lead to lower exhaust gas temperatures, with consequent critical issues with regard to the after-treatment system activation and efficiency. Only in some cases are the technologies improving the thermal efficiency also helpful in reducing emissions, e.g. highly diluted charge motion controlled combustion, microwave ignition.

For this reason combining all the engine and exhaust gas after-treatment systems are a challenging task which needs further and intense research activities. Moreover, the introduction of sustainable fuels introduces new chemistries with further research challenges in this area. Even though there are today already technologies for emission reduction, such as Diesel Oxidation Catalyst (DOC), Diesel Particulate Filter (DPF), NO_x Storage Reduction (NSR) and Selective Catalytic Reduction (SCR), a strong necessity exists for further research into improvements in after-treatment technologies as well as in the improvement of the combustion process itself.

3.2 CO₂ challenges for future Heavy Duty ICE based propulsion

The realisation of the EU GHG targets for 2050 will require from the heavy duty sector a **CO₂ yearly reduction of at least 3% on the complete annual new Heavy Duty Vehicle (HDV) fleet sales in EU, until 2050.**

3% CO₂ reduction needed to meet the challenges for European Heavy Duty Transport

Annual new fleet sales

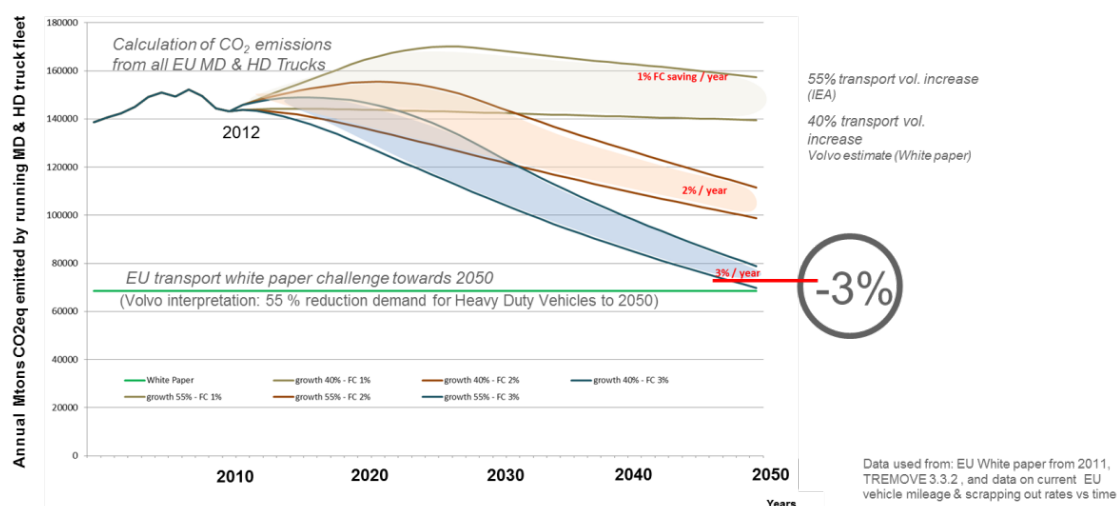


Figure 3.6 From Volvo Keynote paper ICPC 2015 – 1: CO₂ challenges for future HD propulsion

Input data for this analysis by Volvo are the political GHG targets set by the EU white paper at 2050, and analysis from World Energy Outlook’s (IEA) New Policies Scenario 2013. In addition, EU/US transportation data of vehicle usage and mileage-reduction and vehicle

scrapping-out rates vs. time have been used. The conclusion in this analysis shows a current trend of non-sustainable growth of CO₂ and GHG emissions for heavy-duty road freight transport. We face a significant challenge to change the trend in the markets in which we are present in order for the political and societal targets to be met. According to this analysis, the realisation of the GHG targets for 2050 will require a CO₂ reduction of at least 3% on annual new fleet sales.

All aspects of HDV operations need to be scrutinised if these types of targets are to be met from a pure CO₂ and energy balance perspective. Aspects, ranging from utilising low CO₂ footprint energy carriers, improving energy efficiency for the Heavy Duty Engine (HDE), the drive train and the vehicle, as well as improving transport solutions to an overall sustainable level need to be addressed.

The heavy duty engine needs to increase in efficiency both with and without low CO₂ fuel and with or without electrification.

Large scale introduction of alternative fuels is also necessary to accomplish reduction in GHG emissions of the required magnitude, efficiency measures are simply not sufficient. On the vehicle side, aerodynamics, rolling resistance, optimised vehicle loading factor and vehicle operation diversity needs to be worked on.

In order to realise the use of new ICE technologies required to meet the challenging CO₂-reduction targets, a certain level of stability will need to be established over time. Knowledge building, development, market implementation and penetration of CO₂ reduction technologies will take time, especially for heavy duty (HD) trucks. Closer interaction between suppliers of new energy paths, HD product producers, HD propulsion and vehicle operators, as well as society and transportation infrastructure/logistics providers, will also be essential, in order to utilise these technologies.

HD diesel engine research for competitive efficiency needs to focus on future possibilities in basic well known areas of diesel engine efficiency, that are related both to light and heavy duty application. However, as in many development processes, significant research is needed into sub-technologies, separately or in combination, in order to reach new levels of efficiency. The durability demands of HD products require a specific need for HD related research and in the selection of new technology solutions starting with advanced materials.

HD transportation is today increasing over the entire spectrum of operation. Both volume limited transportation is increasing as well as weight limited heavy duty transportation which is being replaced in some areas by long combination transports. The load operation for the HD engine and its performance and efficiency for every transportation need are thus more challenging than before. At the same time plug-in charging electrification, in comparison to light duty transportation, will have low impact on the CO₂ reduction for HD transport, due to the absence of infrastructure or due to the power demand that makes it inefficient. The HD reduction in CO₂ needs thus to be derived from efficiency improvement and by efficient utilisation of renewable fuel and fuel blends.

In summary, to meet this diversity demands HD ICE research needs to focus on areas such as:

- New or modified engine architectures for improved cycle efficiency
- Engine/powertrain systems for longer/heavier combinations
- Heavy electrification (PHEV with electrified major roads)
- Improvement of thermodynamics
- Engine down speeding and/or engine downsizing (where applicable)
- Combustion improvements (cylinder pressure, chamber shape, improved heat rejection, fuel injection)
- For conventional and low carbon fuels; combustion concepts and exhaust gas after-treatment for Natural Gas
- Turbo efficiency/Turbo-compound Waste Heat Recovery
- Waste Heat Recovery in combination with Hybridisation
- Engine friction and fluid pumping
- Ultra-low engine-out emissions control
- Engine control and adaptation for
 - Autonomous vehicles
 - Electrified urban delivery

4 Conclusions and impact

There is a common understanding that more efficient powertrain solutions will find the right environment to penetrate the market only if an integrated approach is ensured at the political level, providing conditions to generate fuel/energy distribution infrastructures, leveraging progressive fleet renewal conditions and supporting customer acceptance through education.

The current fleet of alternative fuelled vehicles in Europe is a share of 5%. New registered vehicles with alternative fuels in Europe have a 2.7% market share. This is clear evidence that ICE technologies will keep its significant role in future propulsion systems for some time.

Furthermore, the optimal powertrain solution is dependent on the vehicle type and use case (e.g. light duty vs. heavy duty, urban vs. interurban) although in general hybridisation seems to be an attractive model.

It is expected, therefore, that the role of the ICE in future powertrains for light and heavy duty vehicles will still be **dominant** (combining conventional and hybrid powertrains) for the next decades. With the average vehicle age of 9 - 10 years for light duty and about 3 - 5 years for heavy duty vehicles in Europe the **impact on reducing carbon emissions** from road transport between 2020 and 2040 through **efficient and optimised ICE systems is significant**. Not forgetting the tremendous quantity of vehicles, which has a large influence on CO₂ and emission reduction even with small progress. Furthermore, new optimisation potential in future ICEs from hybridisation and alternative fuels can be utilised already during this period.

The main objective is to develop an **optimised ICE system solution for future powertrains**; for highly integrated ICE hybrid solutions targeting zero emission, utilising a sustainable renewable fuel at 50+ % conversion efficiency. Providing an on-road efficiency of 70+ %, due to optimal powertrain control and Intelligent Transport System (ITS) integration. There are a number of challenges including increasing thermal efficiency and control of air quality particularly for the light duty side and control of CO₂ for the heavy duty side. There is a global recognition of the need to address these challenges for optimised ICE system solutions.

The **optimised ICE system solution for future powertrains** considering light and heavy duty applications should target the following research topics:

- High efficiency light and heavy duty combustion engine technologies.
- Alternative fuel engines technologies.
- Electrified propulsion and dedicated transmissions.
- Transversal (i.e. control, etc.) technologies and methodologies.

All improvements in ICE technology will have a significant beneficial impact on fuel consumption, on people and goods transport efficiency, on CO₂ output and on emissions reduction, with a wider use of low-carbon fuels (such as natural gas) and renewable fuels (advanced liquid biofuels and different paths for bio and synthetic methane), over an extended period of time. These improvements when integrated with the electrification of vehicles in the form of hybridisation will maximise impact at the lowest cost. Figure 4.1 shows an estimate of the ranges of the magnitude of the CO₂ benefits expected.

Technology	CO ₂ Light Duty benefit	CO ₂ Heavy Duty benefit	Overall 3% per year
Increase of overall thermal efficiency	12% (diesel) – 15% (gasoline)	up to 12%	
Renewable low carbon fuels use	20 - 25%		
Electrification of the ICE powertrain	up to 20%	marginal	

Figure 4.1 CO₂ benefits

The automotive and associated industries will continue to respect their societal responsibilities for sustainable solutions emphasising the need for pragmatic, cost-effective approaches, which ensure true sustainability for environment, economy and society whilst maintaining EU industry competitiveness.



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