Norbert Dressler, Wolfgang Bernhart, Jun Shen,
Stephan Keese, Alberto Fernandez, Frank Pietras

Study

Truck Powertrain 2020

Mastering the CO_2-Challenge

Roland Berger
Strategy Consultants

Norbert Dressler, Wolfgang Bernhart, Jun Shen,
Stephan Keese, Alberto Fernandez, Frank Pietras

Study

Truck Powertrain 2020

Mastering the CO_2-Challenge

Contents

Executive summary

Manufacturers of medium- and heavy-duty commercial vehicles[1)] and their suppliers are gradually starting to recover from the industry's worst crisis since World War II. Now that the storm seems to have blown over, management must turn its attention to the challenges ahead. Two such challenges, for instance, are the dynamics of competition (e.g. increased cost pressure in the markets of Eastern Europe and Latin America due to the rise of Indian and Chinese OEMs) and the development of segments in the triad countries (shift in customers' preferences toward light-duty and heavy-duty vehicles, causing the medium-duty segment to lose out).

One of the most daunting challenges, however, concerns future emissions regulations. Standards due to be introduced are already necessitating huge expenditure on powertrain and exhaust aftertreatment technologies to reduce emissions. Current estimates indicate that European OEMs must each invest between EUR 0.5 and 1 billion for the development of vehicles that meet the Euro VI standard (just the engine development and enhancement of existing vehicles is expected to incur costs of EUR 300 to 500 million). The challenge does not end there, however. One related but much more far-reaching topic is the need to reduce CO_2 emissions – and hence fuel consumption – in commercial vehicles.

Ever since the Euro I standard was introduced in 1992, governments, led by the triad countries, have been battling to reduce emissions of harmful exhaust gases from commercial vehicles. Regulations so far have addressed substances such as nitrogen oxides (NO_x) and particulate matter (PM). Future exhaust emissions regulations are also expected to focus on CO_2 in an attempt to reduce dependency on oil and limit the effect of greenhouse gases. Several nations, including all of the G8 countries, have committed to limiting global warming to a maximum of 2°C. Like all industries that generate CO_2 emissions, the transportation sector and thus the commercial vehicle industry too must do its part to achieve this goal.

We estimate that meeting this target would (theoretically) require an average CO_2 emissions reduction of 25-30% by 2020 for new medium- and heavy-duty vehicles, depending on the development of the overall fleet size and annual average mileage.

With fuel consumption being a major purchase criterion, particularly in the triad markets, vehicle and engine efficiency have constantly improved over time. However, ongoing improvements in conventional powertrains are not enough to achieve the expected CO_2 emissions reduction.

1) This study focuses on vehicles with GVW over 6 ton

Radical changes in vehicle design and aerodynamics are needed – as are new alternatives to conventional ICE powertrains. A range of alternatives are available to help meet the emissions requirements already in place and the anticipated CO_2 regulations. These include hybrid and electric powertrains as well as H_2O fuel cells. Increased use of alternative fuels would further contribute to reduced CO_2 emissions. However, not all technologies will encounter the right conditions to achieve mass application. Fuel cells, for instance, are regarded as less attractive due to high costs, a complex production process and high maintenance requirements. Moreover, the right technology mix will also depend on the region and vehicle segment in question.

In urban fleets, even with the most optimistic scenario regarding combustion engine improvements and alternative fuels, hybrids will be essential if fuel consumption is to be reduced significantly. In emerging markets, where conventional powertrains do not yet match the quality of those in their triad counterparts, local OEMs can benefit from proven technologies. These include optimized transmissions to reduce fuel consumption without immediately having to introduce complex alternative powertrains.

As a prerequisite, manufacturers must reduce system costs by realizing synergies across regions and vehicle segments. Moreover, national and local governments must create effective incentive and penalty programs to make the purchase of alternative hybrid systems attractive to customers. It is therefore up to governments and OEMs to decide whether they want to go a step further and introduce alternative technologies in their markets.

Essentially, three main conclusions can be drawn from an analysis of the markets and alternative technologies:

1. Diesel (with different primary energy chains) will remain the predominant fuel source for medium- and heavy-duty commercial vehicles through 2020, both in the triad and emerging markets

2. In the triad markets, the use of both alternative powertrains and alternative fuels as well as further measures regarding truck/trailer combinations (e.g. aerodynamic improvements, reduced rolling resistance, wast heat recovery)[2] will be needed to achieve an average new vehicle CO_2 emissions reduction of 25-30% by 2020. This means a significant share of hybrid vehicles in the city transport segment and significant vehicle improvements in the long-haul segment. The latter segment is particularly important due to a larger vehicle stock and higher fuel consumption

2) Other external factors such as driving behavior, infrastructure improvements, etc. also help reduce CO_2 emissions but are not in focus of this study

3. In emerging markets, upgrading combustion-based powertrains (incl. engine, transmission and axles) to the current standard of those in the triad markets and promoting the replacement of old vehicles would help deliver a major reduction in CO_2 emissions from commercial vehicles

In light of these findings, both governments and market players must map out comprehensive CO_2 strategies to successfully reduce emissions. Governments must take the following action as part of their strategies:

> Define appropriate universal methods for measuring CO_2 emissions from commercial vehicles while reflecting the complexity of the vehicle application

> Set transparent CO_2 emissions reduction targets as soon as possible to give the industry a clear framework to work in

> Modify regulations (e.g. maximum vehicle length/weight) to enable maximum efficiency with existing standard technologies (e.g. aerodynamics)

> Draw up an appropriate overall strategy to create incentives for the development and introduction of alternative technologies, as well as for the replacement of older vehicles (especially in emerging markets) in line with defined emissions reduction targets

For their part, triad-based OEMs and system suppliers face a tough dilemma. On the one hand, they have to develop hybrid or other systems to comply with the expected targets. On the other hand, they must master the resultant technological complexity and produce sufficiently high volumes to reduce costs. A coherent CO_2 strategy is imperative if the market players affected by CO_2 regulations are to succeed in the medium term. Such a strategy must include the following elements:

> Plot a technology roadmap and redefine internal competencies

> Define a global modular system to realize scale effects within vehicle segments and regions

> Establish alliances with selected OEMs/suppliers to reduce risks and minimize R&D expenses

> Collaborate with other industry players to define global standards for new components such as batteries

> Map out a supply chain strategy that can deal with potential bottlenecks

> Prepare an effective marketing/communication strategy

> Plan the overhaul of sales and service networks that will be needed to accommodate electric powertrains

> Create a central position with responsibility to oversee CO_2 reduction efforts in different functions

Market players based in emerging markets also need to prepare an overall CO_2 strategy. They can choose between two approaches with respect to alternative powertrains:

> Front runners and innovators can capitalize on early market entry with a new powertrain technology. This approach targets a larger market share and greater brand recognition, but also entails significant upfront investment and expenditure. Government incentives such as finance for R&D are therefore vital

> Followers can minimize short-term risks and investment volumes by adopting technologies that have already proven themselves on the market. This approach involves less upfront expenditure, but also promises a smaller market share in the initial years after the launch of a technology

The first strategy is now being pursued by Chinese passenger car OEMs, for instance. Supported by sizable government subsidies, these companies are already targeting the triad markets with their electric vehicles. Looking at the incentive programs put in place by the Chinese government for hybrid and electric city buses, it is reasonable to assume that a similar strategy will be pursued by their commercial vehicle counterparts.

Ambitious CO_2 emissions reduction targets are expected to be defined in the near future. Market players should seize the opportunity now to meet this challenge and pave the way for their success in the future.

Introduction

Intensifying debate about global warming and dependency on oil is driving a massive push to reduce fuel consumption and CO_2 emissions. With the Copenhagen Accord acknowledging the need to take action to restrict global warming to 2°C this century, further governmental effort is necessary. Stricter prescribed limits to reduce CO_2 emissions are the subject of much debate. As the transportation sector is a major producer of CO_2 emissions, corresponding targets are expected for the commercial vehicle industry in the near future. The triad markets will be the first to act, and emerging countries will inevitably follow suit.

For commercial vehicle manufacturers and their suppliers, it is vital to grasp the implications of this new undertaking. Likewise for government officials who concern themselves with environmental topics, it is very important to understand the consequences their policies will have for different market players if critical disruptions due to inappropriate emissions regulations are to be avoided.

Our aim in this study is to shed some light on a number of pressing issues. First of all, how will regulatory standards for commercial vehicle emissions develop in the future? Second, what longer-term technological options are available to help OEMs comply with emission limits? Third, how will market requirements influence the development of low CO_2 emissions technologies? And finally, what must market players do today to master the challenges of tomorrow?

This study focuses on on-road medium- and heavy-duty trucks with a gross vehicle weight (GVW) of over six tons. It covers the triad markets as well as Brazil and China, from which conclusions can be drawn for the broader spectrum of emerging markets. Regarding levers to reduce CO_2 emissions, the study concentrates on actions that affect vehicle performance independently of external factors such as driving behavior or traffic congestion relief.

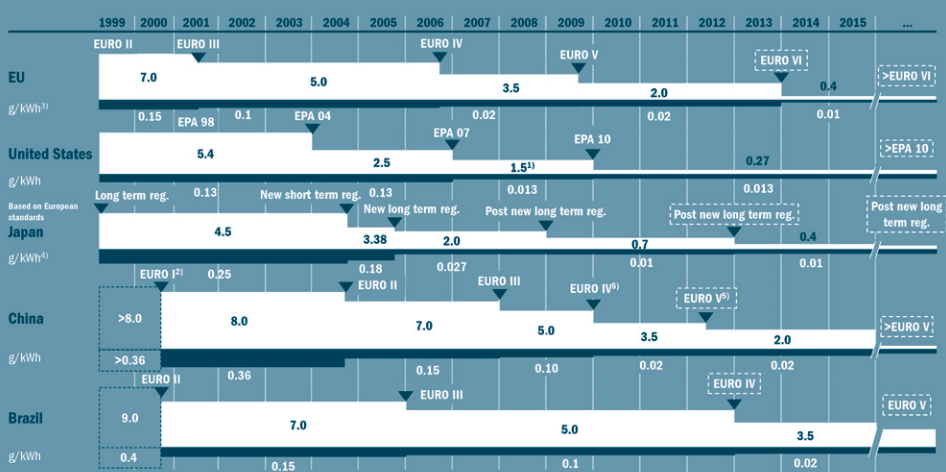
We interviewed more than 50 top executives from truck OEMs, suppliers and experts from regulatory organizations in order to validate our hypotheses. Our conclusion? That it is impossible to overstate the impact that expected developments from CO_2 emissions regulations could have on OEMs and suppliers in this industry. How players prepare for these challenges today will shape their market performance for a long time to come.

1. Regulatory environment: How will regulations influence the market penetration of CO_2 emissions reduction technologies?

1.1. CO_2 emissions reduction targets – Status and expectations

In the recent past, governments have launched a wide range of individual programs to reduce commercial vehicle emissions. OEMs have made significant efforts to fulfill the resultant requirements. Historically, Europe and the US have so far driven the implementation of stricter standards, followed by emerging countries, which are currently several years behind them. Looking ahead, the international community is expected to take further steps toward introducing harmonized binding emissions targets.

Figure 1: Development of medium- and heavy-duty commercial vehicle emissions regulations



Note: Carbon monoxide (CO) and hydrocarbons (HC) are also subject to regulations; not shown here

1) Only 50% of group sales have to comply with NO_x standard; 100% in 2010 2) Introduced in Shanghai in 1999
3) Refers to introduction of regulation for all vehicles (first-time registrations) 4) Introduction dates for vehicles >12t 5) Implementation dates vary between cities/regional areas

Source: Press clippings; Diesel Net; Delphi; government websites; Roland Berger

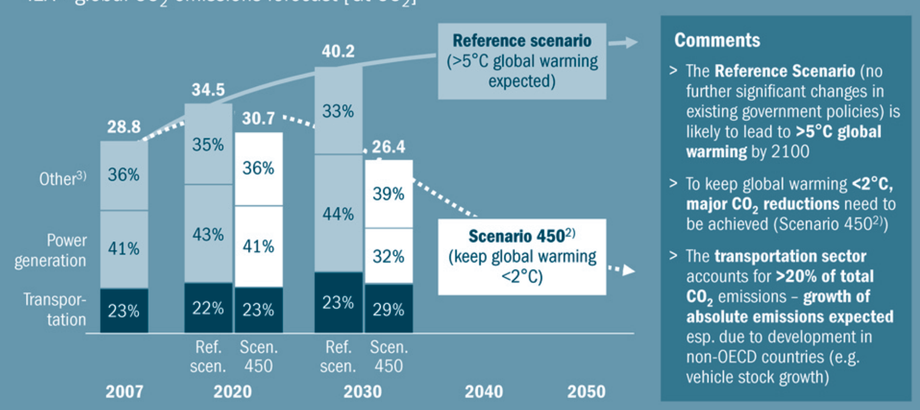
The primary focus of commercial vehicle emissions regulations has so far been on substances such as nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM). That said, the truck industry now expects a further raft of regulations centered on CO_2 emissions and fuel efficiency. Following the road already taken by passenger cars, the world's most important truck markets are thus likely to see (binding) CO_2 emissions targets introduced for commercial vehicles over the next decade.

Current public debate clearly shows the extent to which pressure is building up from governments and society to reduce CO_2 emissions on a broad scale. Driven by the twofold aim of reducing dependency on oil and curbing greenhouse gas emissions (and hence global warming), governments are increasingly promoting alternative energy. Over 100 countries worldwide have committed to limiting global warming to 2°C in the long term under the Copenhagen Accord. Though these steps are non-binding and probably ultimately inadequate, they are nevertheless the first fruits of the emerging trend.

In its 2009 World Energy Outlook, the International Energy Agency presented two theoretical scenarios for the development of global energy-related CO_2 emissions in the coming decades. The **Reference Scenario** assumes the absence of new governmental initiatives to address global warming by reducing CO_2 emissions. **Scenario 450**, by contrast, takes account of the positive influence of a specific target set both for global emissions and emissions by individual sectors. The assumption underlying Scenario 450 is that greenhouse gas concentrations in the atmosphere can be stabilized at 450 parts per million CO_2 equivalent. The Reference Scenario would result in a 40% increase in annual carbon emissions through 2030, probably driving up the global temperature by more than 5°C this century. However, Scenario 450 would lead to an overall reduction of CO_2 emissions after 2020 – and would probably keep the increase in global temperature below 2°C.

Figure 2: Global CO_2 emissions scenarios (IEA)

IEA[1] global CO_2 emissions forecast [Gt CO_2]



1) International Energy Agency 2) 450 parts per million CO_2 equivalent in the atmosphere
3) Mainly CO_2 from industrial production, buildings and households

Source: IEA World Energy Outlook 2009; Roland Berger

Bearing in mind the resultant theoretical requirement to reduce emissions, future government regulations will have to be ambitious. Compliance will present a stiff challenge to the industries concerned. Specifically, to achieve the CO_2 reduction simulated in Scenario 450, literally every industry from transportation (which accounts for almost one fourth of all energy-related carbon emissions) to power generation and even private households would have to contribute.

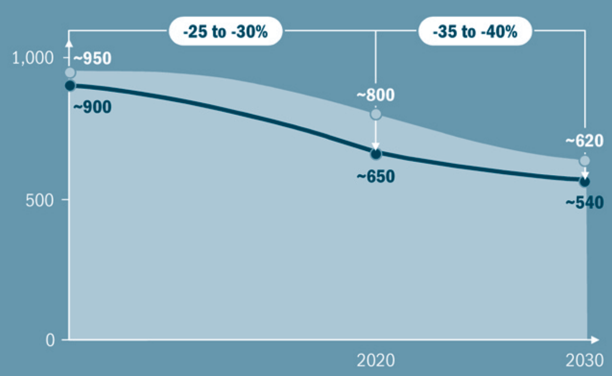
In the transportation sector, the impact on passenger cars and light commercial vehicles will be particularly dramatic. These are the largest single emitters in this sector, accounting for approximately 44% of all carbon emissions in transportation. Intense public discussion of the need to cut CO_2 emissions has led the EU to target a gradual reduction from 161 g CO_2/km in 2006 to 130 g CO_2/km in 2015 for new passenger vehicles (100% of fleets). In addition, the EU has proposed a target of 175 g CO_2/km for light commercial vehicles below 3.5 ton in 2016 (100% of fleets). By 2020, the fleet CO_2 limit will be 140 g/km. For medium- and heavy-duty vehicles, the writing is on the wall: At the latest in the medium term, they too will probably have to face up to CO_2 emissions regulations.

Based on the IEA's calculation for Scenario 450, CO_2 emissions from the existing fleet of medium- and heavy-duty vehicles would have to be significantly below the Reference Scenario in 2030. Assuming a specific percentage contribution from each vehicle segment and using a simplified model that takes into account the projected trend in medium- and heavy-duty commercial vehicle numbers, we estimate the required emissions reduction to be approximately 35% in 2030 for the total fleet compared to 2008. Achieving this target implies an average reduction of CO_2 emissions from new vehicles of 25-30% by 2020 and about 40% by 2030 (see figure 3). Such a sharp drop would naturally require much greater fuel efficiency.

Bearing in mind these assumptions, we need to examine the implications of a binding target for CO_2 emissions reductions for different industry players – on a technical as well as a strategic level. We must also investigate how such a target might be implemented, and where and when we can expect the introduction of such regulations for commercial vehicles.

Figure 3: Simulation of medium- and heavy-duty vehicle CO_2 emissions over time

Required global CO_2 fleet emissions for medium- and heavy-duty commercial vehicle stock and new vehicle fleet [g/km] – Illustration



Comments

- Simplified **simulation** of required CO_2 emissions to comply with IEA Scenario 450 (depending on vehicle stock development)
- **Old vehicles** in stock will be **replaced** by new vehicle fleet, reducing overall CO_2 emission level
- **CO_2 reduction technologies** are required for fleet (alternative fuels) and new vehicles (alternative fuels, ICE powertrain/vehicle improvements, alternative powertrain technologies)

Average CO_2 emissions for vehicle stock — Average CO_2 emissions for new vehicle fleet

Source: Roland Berger

1.2. Requirements for enforcing CO_2 regulations

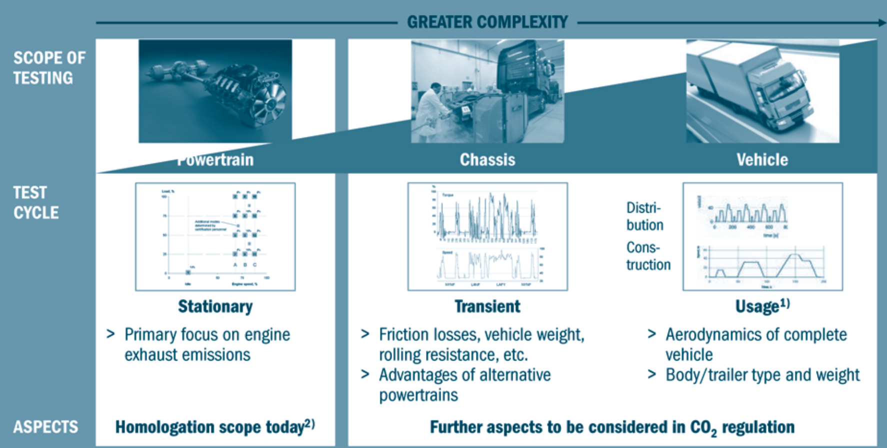
The task of defining fair, standardized CO_2 reduction and fuel efficiency targets is more complex for medium- and heavy-duty commercial vehicles than for passenger cars. The reason? In the case of commercial vehicles, you also need to consider usage.

The usage of commercial vehicles has a major influence on fundamental vehicle characteristics such as cab size, vehicle weight and, of course, fuel consumption. Any measuring or limitation of CO_2 emissions of commercial vehicles must therefore consider the different driving modes and ranges found in specific segments (long-haul trucks, city/delivery trucks, construction vehicles, etc.).

These specifics of vehicle usage must be reflected in the test cycles applied. Today, stationary or at best transient cycles are used. These do not measure actual CO_2 emissions accurately enough to serve as a basis for regulation. Before comprehensive targets are set, specific test cycles must be defined that take into account issues such as specific driving modes and vehicle load and weight (g CO_2/km versus g CO_2/ton/km).

The scope of testing – which must also be factored into any definition of the "proper" way to measure CO_2 emissions – is therefore an essential aspect. Current homologation (or "type approval") tests only take account of the vehicle engine. Technologies that are already available or in development to reduce carbon emissions in trucks must also be considered when setting emissions limits for commercial vehicles. These include electrification, vehicle and trailer aerodynamics, weight reduction, rolling resistance, and so on. To take all these factors into account, homologation processes have to involve testing the entire vehicle (including the superstructure and trailer), not just the powertrain and the chassis, say.

Figure 4: Homologation scope for commercial vehicles



1) Vehicle usage (long-haul, distribution, etc.) factored into CO_2 emissions measurement/simulation
2) Some regions already use transient cycles today

Source: Interviews; Roland Berger; Pictures: Scania Image Bank © 1999, test facility European Commission 2009

Due to this complexity, adequate measurement of CO_2 emissions for commercial vehicles would necessitate significant investment in expanding vehicle testing facilities worldwide. Accordingly, it is expected that simulations (rather than actual measurements) will be used to provide estimates. Engines and powertrains will, however, continue to be tested on real test beds to ensure compliance with emissions standards for other pollutants. The conditions under which both simulations and real tests are conducted directly influence the design of the aftertreatment system and several engine components. This makes it crucial to have the relevant testing conditions harmonized on a global level in the future to enable synergies to be realized across regions. Homologation test cycles, for instance, are already converging for medium-duty and heavy-duty commercial vehicles under the lead of the World Forum for Harmonization of Vehicle Regulations.

This United Nations working party has developed what is known as the World Harmonized Transient Cycle (WHTC), proposed for the homologation of future engines. Further harmonization work of this type is needed if governments are serious about helping OEMs minimize the financial outlay involved in reducing harmful emissions.

1.3. Instruments for implementing CO_2 regulations

Once a suitable method of measuring CO_2 emissions has been agreed, it is expected that segment-specific fuel efficiency targets will be set for major markets relatively quickly. To ensure that the targets are widely met, governments need to adopt a twofold approach (see figure 5):

Supply side: OEMs and suppliers should be encouraged to adjust their products and R&D focus in order to meet fleet emissions targets. Experience from passenger cars shows that a carrot-and-stick approach works best: combining tax penalties with initial subsidies. To speed up technological development and cultivate expertise in this sector longer term, specific incentive programs and subsidies for R&D have already been introduced in some regions, as have programs aimed at ramping up volume production of new technologies. These activities are only a starting point, however, and are expected to be scaled back in the medium term.

Demand side: Governments must also stimulate greater customer demand for environmentally friendly technologies. This can be done with a combination of national programs (such as tax incentives) and local activities (such as congestion charges linked to vehicle fuel consumption).

Figure 5: Government levers for achieving CO_2 reduction targets

Government levers for meeting CO_2 reduction targets

A) SUPPLY SIDE

> **Regulations to determine reduction targets**
  – For vehicles, maximum CO_2 emissions/fuel consumption targets for new vehicles
  – For fuels, compulsory admixture of alternative fuels to diesel

> **Incentives for R&D and industry**
  – Funding R&D programs
  – Tax benefits for companies involved in the development of low CO_2 emission technologies

TARGETS

Reduce CO_2 emissions for
> Existing vehicles
> New vehicles

B) DEMAND SIDE

> **Tax breaks and incentives**
  – One-time tax breaks/incentives (on vehicle purchase prices)
  – Annual taxes
  – Fuel prices and road tolls

> **Local actions**
  – Additional benefits for fuel-efficient technologies
  – Congestion charges for vehicles above a specific CO_2 emission threshold (city tolls)

Source: Roland Berger

Numerous examples of both approaches can already be found in the world's major commercial vehicle markets. On the **supply side**, discussions about CO_2 targets for medium- and heavy-duty commercial vehicles have already begun in various regions, following the same road taken by passenger cars:

> In the **US**, for instance, CO_2 emissions regulations are expected to be announced within the next three years. 2016 is regarded as a realistic target for nationwide implementation, which will involve an initial reduction of approximately 10% in fuel consumption followed by further gradual reductions. The government's recent announcements concerning an intensified focus on fuel-efficiency for trucks lend credence to these expectations

> The **Japanese** government has already set fuel efficiency targets for new commercial vehicles that must be met by 2015. Trucks with a GVW of 16-20 tons, for example, will have to consume less than approximately 24 l/100 km. Depending on the engine, this means a reduction of up to 20% compared to today

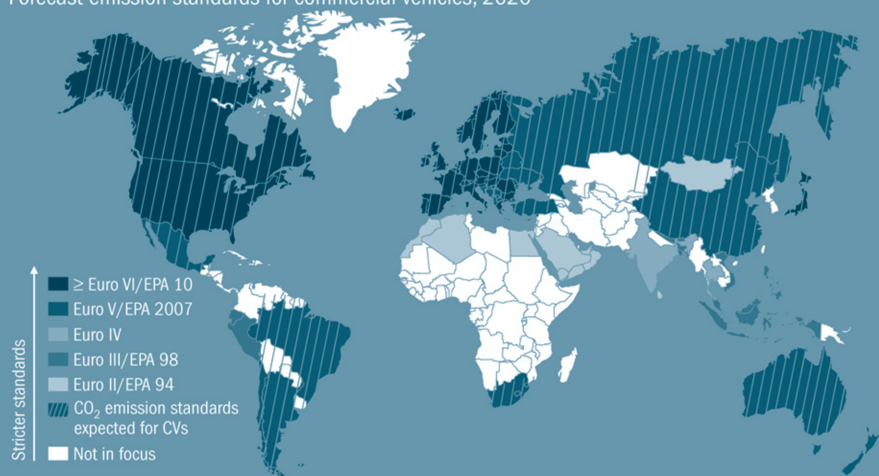
> In the **EU**, a comparable process is expected in the near future with full enforcement by 2020

> As with emissions regulations in the past, **emerging markets** are expected to follow the triad markets' lead in the case of fuel efficiency targets. China, the world's largest truck market, is expected to set targets – at least for certain commercial vehicle segments – before 2020. Discussions about buses have already begun. As in the case of national emissions standards in the past, major cities such as Beijing, Shanghai and Hong Kong are expected to pioneer the introduction of new standards, with the rest of the country lagging behind

Looking at the lead given by the passenger car sector and public pressure to reduce carbon emissions worldwide, the introduction of CO_2 emissions targets for the commercial vehicle sector now seems inevitable. By 2020, most countries will already have agreed on stricter standards, with prescriptive CO_2 emissions thresholds for medium- and heavy-duty commercial vehicles expected in most major truck markets.

Figure 6: Forecast emissions standards for commercial vehicles, 2020

Forecast emission standards for commercial vehicles, 2020



Source: Delphi; DieselNet; press clippings; Roland Berger

Another regulatory aspect that must be borne in mind when talking about reducing CO_2 emissions in commercial vehicles is the compulsory admixture of biofuels to diesel. Several regions have already implemented standards governing this practice (see figure 7). As more and more countries launch programs to curb carbon emissions, this area is expected to gain importance.

Figure 7: Regional regulations on the admixture of biofuels to diesel

Compulsory admixture of biofuels to diesel

EU	US	Japan	China	Brazil
> Legislation for admixture of biofuels varies among member countries > Biofuel target of 5.75% addition in 2010[1] – further increases expected with 2nd-generation biofuels (compatibility issues with ICE)[2] > 10% binding target for biofuel consumption by 2020 planned	> Currently no national regulation on admixture of biofuels to diesel > Several state and federal laws promote use of biofuels, including biodiesel > Biomass-based diesel will become part of Renewable Fuel Standard Program by 2013 (final EPA ruling pending)	> Currently no national regulation on admixture of biofuels to diesel > Increased domestic production target for biofuels – but no specific mandatory blending rate for biodiesel expected in medium term	> Currently no national regulation on admixture of biofuels to diesel > Biomass fuel is promoted in general terms in the Medium- and Long-term Development Plan for Renewable Energy	> Admixture of 4% biodiesel currently prescribed > Biofuel content in diesel increased to 5% effective January 2010 > Government proposal to gradually increase biodiesel content in diesel to 20% in big cities by 2015 (approx. 10% expected for rest of the country)

1) % energy, includes biofuels and ethanol 2) Internal combustion engine

Source: Press clippings; government information; Roland Berger

On the **demand side** too, progress can be seen in various regions. Governments and local authorities in most major commercial vehicle markets already promote fuel-efficient vehicles and the use of alternative fuels in one way or another. Efforts to stimulate customer demand do not tend to focus on any one specific technology (such as hybrid engines, electric vehicles or fuel cells). However, this also makes it difficult to measure the impact of such programs on future technology development in a specific region.

There is no shortage of examples of demand-side tools being used:

European Union

> Local authorities are creating more and more low-emission zones in major cities. These zones prohibit access for diesel-powered trucks and coaches with less strict emission standards, for example, or levy fees according to a vehicle's emissions category. This creates a powerful incentive for operators to exclude older vehicles with higher emissions from their fleets. The city truck segment in particular is expected to be heavily influenced by this development

> Toll schemes related to emission levels for commercial vehicles are another example. Such schemes have increased the proportion of modern, cleaner vehicles using German highways over the past few ears. According to the German Federal Office for Goods Transport, the share of mileage by trucks complying with the Euro V standard passed the 50% mark in 2009, although the standard only became mandatory in September 2009

US

> Tax credits are used to promote the sale of new, more fuel-efficient vehicles. For heavy-duty hybrid vehicles, local tax breaks can be as high as USD 18,000. Federal and state policies also aim to reduce the cost of biofuels and increase their availability, focusing primarily on ethanol. At the same time, anti-idling laws at state level carry penalties for non-compliance. These laws are driving the electrification of several components (such as HVAC systems) in commercial vehicles

Japan

> Higher taxes penalize the owners of vehicles that are more than 11 years old, thereby stimulating demand for new commercial vehicles that are usually more fuel-efficient

China

> Government actions include subsidies for public buses depending on the powertrain technology used and the level of fuel efficiency. Recently the number of cities defined as test regions within government programs has increased from 13 to 20. Subsidies are granted for hybrid vehicles, electric vehicles and fuel-cell buses

Brazil

> Cities such as São Paulo and Sorocaba have introduced emissions inspections for pre-owned commercial vehicles, as a way of preventing excessive emissions. Additionally, funding incentives promote the use of electric and fuel-cell vehicles in public transportation

Demand-side programs such as tax incentives and subsidies make new technologies more attractive to customers. At the same time, they mitigate the current financial disadvantages arising from high costs and limited commercial availability.

Both demand-side and supply-side tools are crucial since they function as a catalyst to new technologies that reduce carbon emissions in the medium- and heavy-duty commercial vehicle sector.

1.4. Summary

To limit global warming to 2°C this century, every industry will be called upon to play its part in reducing CO_2 emissions. In the transportation sector, this job will not be left to passenger cars and light-duty commercial vehicles alone: medium- and heavy-duty commercial vehicles are likely to have to shoulder their share of the burden too. Based on a simplified model, we estimate that new medium-duty and heavy-duty commercial vehicles would theoretically have to reduce their average CO_2 emissions by 25-30% by 2020.

Over the next decade, governments in the largest truck markets – again led by the triad markets – are therefore likely to introduce binding CO_2 emissions regulations to help substantiate their existing carbon reduction commitments. They have already started to take isolated steps to generate demand for technologies for reducing CO_2 emissions in commercial vehicles and stimulate supply, primarily in the public transportation and city truck segments. Such steps are likely to be intensified in the context of current discussions about global warming and will act as a catalyst, gradually enabling CO_2 emissions reduction technologies to be built into greater numbers of commercial vehicles.

A significant volume of alternative powertrain technologies, vehicle improvements and alternative fuels is therefore essential if anticipated carbon reduction targets for commercial vehicle fleets are to be met by 2020.

2. Challenges to be overcome: Which technologies will meet future regulations while providing financial benefits for customers?

2.1. Introduction

Based on initial assumptions, average CO_2 emissions for new commercial vehicles will – depending on vehicle park development and annual mileage – have to be slashed by up to 30% by 2020 (taking 2008 as the base year). Achieving this target constitutes a major challenge for the commercial vehicle industry. Although the specifics of upcoming regulations remain unclear, it can be expected that CO_2 emissions reduction targets will be generally enforced within the next 5-10 years.

Commercial vehicle technology has advanced in leaps and bounds in recent decades. Now, however, technology has reached the point where tweaking conventional ICE powertrains can no longer materially improve fuel consumption in fleets deployed in the triad markets. Two things are needed to achieve the necessary reductions: radical changes in vehicle design, and the use of alternative technologies such as hybrid/electric powertrains, fuel cells and alternative fuels.

Getting all these technologies to market will entail enormous upfront expenditure in R&D and huge investments in adapting production and aftersales networks – not to mention the cost of managing a quantum leap in complexity. OEMs and suppliers must carefully analyze the potential of each technology. Only then can they set the right priorities and meet the expected CO_2 emissions reduction targets while minimizing their own investment.

Having analyzed the potential of each technology, we identify three key challenges that must be overcome to achieve broad market penetration:

1. The real ability to reduce CO_2 emissions and thus meet carbon emissions targets

2. The widespread commercial availability of technologies, focusing in particular on aspects such as safety and the need to expand distribution infrastructures in order to drive market penetration

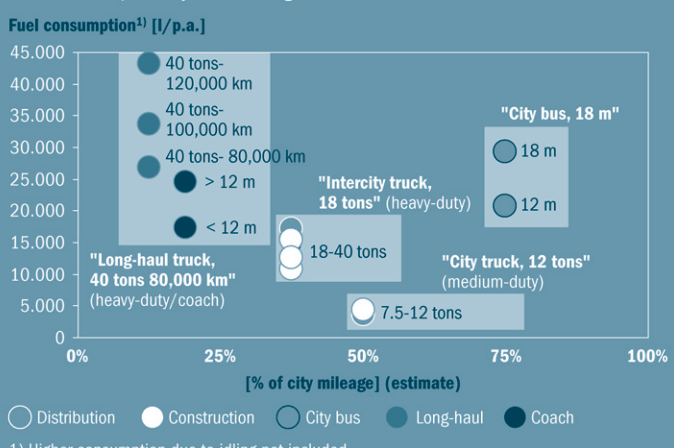
3. Financial benefits for customers based on the total cost of ownership (TCO), i.e. all the vehicle operating costs, including maintenance. Ultimately, customers will only accept technologies that positively impact the TCO

The right mix of technologies can only be defined for specific vehicle segments. Improved aerodynamics, for example, can significantly impact fuel consumption in the long-haul vehicle segment, but would make very little difference to low-speed urban traffic.

Figure 8 segments the German vehicle fleet based on annual fuel consumption (average fuel consumption multiplied by annual mileage) and share of urban mileage (i.e. mileage that involves a large proportion of low-speed driving time and frequent start-stop maneuvers). Accordingly, vehicle applications are grouped into four major segments, each with one representative vehicle chosen for detailed analysis: a 12-ton medium-duty delivery truck in the city segment, an 18-ton distribution vehicle in the intercity segment, an 18-meter articulated bus in the city bus segment, and a tractor-trailer combination with 40-ton overall GVW in the long-haul segment. Since these segments cover virtually the entire fleet (with the exception of a few highly specialized applications such as bucket trucks), they may be regarded as representative.

Figure 8: Vehicle fleet segmentation

Fuel consumption by vehicle segment in German fleet



1) Higher consumption due to idling not included

Source: Lastauto Omnibus; Dekra; Roland Berger

Comments

- Commercial vehicles segmented as a function of their **absolute fuel consumption** and **usage** (estimated percentage of city mileage)
- **Fuel consumption** in l/p.a. based on average fuel consumption/100 km (assuming average loads **based on empirical values**) and mileage/p.a.
- Tractor trucks (long-haul) account for over 30% (~170 k units) of medium- and heavy-truck stock; city bus/coaches only for a minor position

Various levers can be activated to reduce commercial vehicle fuel consumption and thus CO_2 emissions. With regard to the expected future CO_2 emissions reduction targets, authorities should focus on aspects that they can directly control, such as optimized vehicle design, and ensure that they are genuinely effective.

The impact of such actions on CO_2 emissions can then be measured during the homologation process. Below, we focus on the optimization of conventional technologies, particularly the **optimization of ICE powertrains, vehicle improvements** and alternative technologies, including **hybrid, electric** and **fuel-cell vehicles** and **alternative fuels**.

Other measures that affect vehicle performance and which are dependent on external factors include driver training (learning to drive in a fuel-efficient manner), driver support features (for example eHorizon), telematics services for fleet management (which help increase average vehicle load) and improving road infrastructure as a way of reducing traffic congestion. Although these are all valid ways of cutting fuel consumption, it is difficult for governments to quantify their effect. This study therefore focuses on the aforementioned improvements that vehicle manufacturers and suppliers can directly influence and which will have a direct impact on vehicle characteristics.

2.2. ICE powertrain improvements

Improvements to the conventional ICE powertrain focus above all on minimizing energy losses. Broadly speaking, there are three main ways to do this: optimize the engine's thermodynamic efficiency (e.g. improve combustion by using high-pressure injection systems); reduce mechanical friction in the engine and the entire vehicle; or optimize the interplay between the various elements of the powertrain (engine, transmission and drivetrain). Examples of powertrain improvements include automatic transmission systems, common rail technology, variable valve trains and the optimization of lubricants.

In light of the significant advances already achieved in the triad markets – for example, the average fuel consumption of a 40-ton long-haul truck in Europe has decreased by over 30% since the 1970s – on average, further optimization is unlikely to deliver additional gains of much more than 5% in the long-haul segment. For ICE powertrains in theory, various optimization measures may well reduce fuel consumption by up to 10%.[3)]

But other factors such as the introduction of future emission norms will counteract this positive effect. The Euro VI standard alone will cause fuel consumption to increase by at least 5%, not least because of the introduction of a diesel particle filter that needs diesel fuel for regeneration, and the extra cooling needed to compensate for the introduction of exhaust gas recirculation systems.

3) See "Shell LKW-Studie", April 2010

Figure 9: Technologies to improve ICE powertrains in the triad markets

Selected powertrain improvements to reduce commercial vehicle CO_2 emissions in triad markets

		Automated transmission	Waste heat recovery	Ancillary units	Other[1)]
	City truck, 12 tons	✓		✓	✓
	Intercity truck, 18 tons		✓	✓	✓
	City bus, 18 meters			✓	✓
	Long-haul truck, 40 tons		✓	✓	✓

Comments

> New emission standards have a **negative impact** (e.g. Euro VI)

> **Automated transmissions** offer **considerable potential** but have already penetrated certain segments

1) E.g. Optimized turbochargers, injection systems with very high pressure

Source: Company information; ACEA; Rocky Mountain Institute; Shell Lkw-Studie, April 2010; press clippings; interviews; Roland Berger

Not all technologies for long-haul truck engines will be applicable in other segments. In some cases, technical aspects will prevent the innovations from being deployed across different vehicle segments. Thus the temperature needed to make a wast heat recovery system work properly is not always reached in urban cycles. In other cases, economic considerations will be the primary obstacle. The heavy R&D expenditure needed to get innovations in internal combustion engines ready for volume roll-out is one example, as is the lower mileage in other segments.

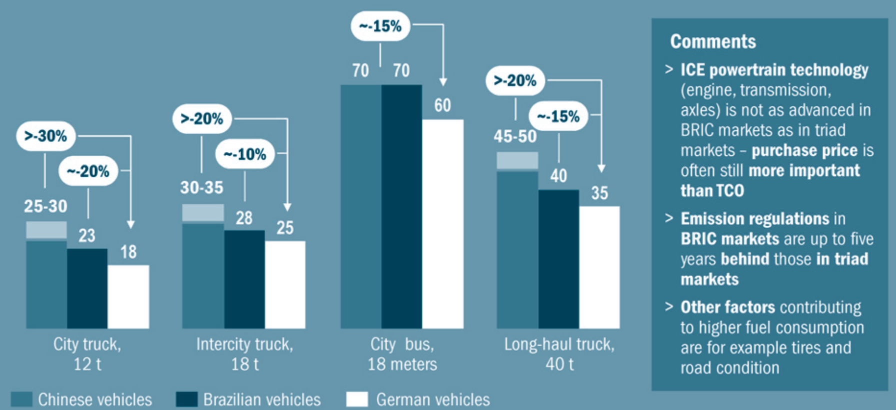
While some innovations (such as automated transmissions) are already on the market, many others (such as thermal management systems) are still in the prototype stage. Furthermore, regional and segment-specific customer requirements will limit the global application of some innovations, thereby hindering economies of scale and leading to higher product costs.

By contrast, significant improvement potential can be exploited in the BRIC markets by upgrading powertrains in line with the state-of-the-art technologies currently available in the triad markets. Figure 10 shows the average fuel consumption of comparable vehicles in China, Brazil and Germany. Differences of between 10% and 30% in fuel consumption are observable today. Less advanced transmissions, axles and lower quality tires as well as driving behavior, the customary overloading of trucks and other regional factors such as topography explain part of this discrepancy.

However, the use of cheaper but less efficient powertrains (engine, transmission, etc.) is also a major factor. Further potential lies in the optimization of the combustion process. Euro II/III powertrains are optimized to minimize the generation of NO_x particles, but lead to higher fuel consumption. Increasing the efficiency of combustion can significantly reduce CO_2 emissions. The downside of the latter approach is that more expensive after-treatment systems are required to meet the post-Euro III standards for other pollutants such as carbon monoxide.

Figure 10: Average fuel consumption of vehicles in China, Brazil and Germany

Average fuel consumption of vehicles in China, Brazil and Germany, 2009 [l/100 km]



Source: Brazilian OEMs; Chinese OEMs; interviews; Lastauto Omnibus

However, one question remains: Why don't Chinese OEMs, for example, already offer triad level powertrain technology on the markets they serve? In fact, apart from the increase in purchase price – which customers are unwilling to accept – BRIC markets need to overcome a number of other challenges before they can adopt current triad technologies.

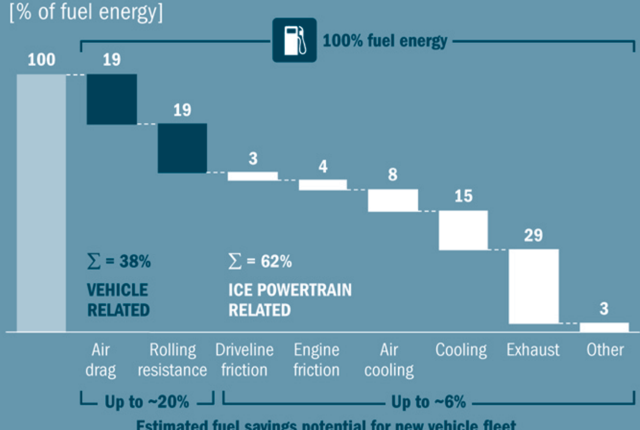
First, some large Chinese truck OEMs have a very high degree of vertical integration and lack the internal capabilities to develop state-of-the-art powertrains. Joint ventures with triad OEMs or engine suppliers, which can increasingly be observed in China, could provide a solution here. Second, there is the requirement to improve the quality of the fuel (diesel with low sulfur, water and residues content) to enable a more efficient combustion process. And last but not least, there is the task of enabling those working in the after-market to service more complex technology.

2.3. Vehicle improvements

Vehicle improvements help reduce fuel consumption by optimizing non-powertrain elements such as aerodynamic properties, total vehicle weight, tires, and so on. Besides heat loss, **air drag** and **rolling resistance** consume by far the largest single share (almost 40%) of the energy generated in the combustion process during highway driving (see figure 11). It thus stands to reason that efforts to improve overall fuel efficiency, particularly for long-haul trucks, should focus primarily on these key aspects.

Figure 11: How long-haul trucks consume energy

Energy usage by long-haul trucks fitted with conventional internal combustion engines [% of fuel energy]



Comments

- Vehicle improvements focus on reducing **rolling resistance** (e.g. tires, weight) and **air drag** (e.g. side skirts)
- Further improvements can be achieved by reducing **usage of the combustion engine** (e.g. by using more electric components)

Source: Renault; Daimler; Roland Berger

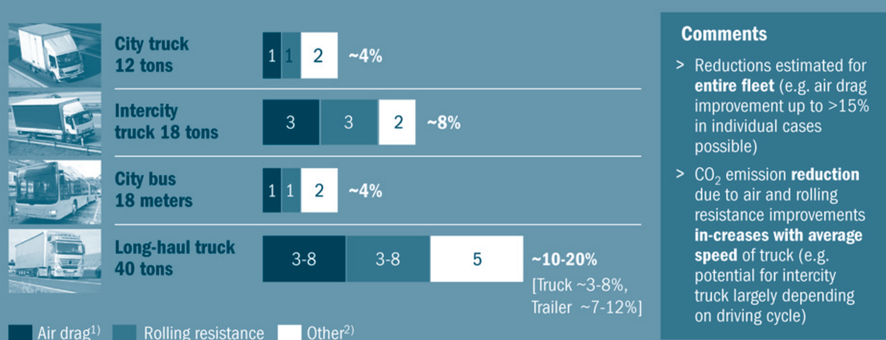
More widespread use of existing features such as roof spoilers, low-resistance tires and LED lights as well as modern tire pressure management systems would certainly allow further reductions in fleet CO_2 emissions. Another example of vehicle improvements that are already available are auxiliary power units that are uncoupled from the engine. Such units can power air-conditioning systems during driving breaks on the highway, for instance.

Looking beyond the standard options available right now, significant potential is found in introducing further improvements such as optimized aerodynamics, a smaller number of tires and lightweight designs. With the help of specific concepts, greater fuel savings and reductions in CO_2 emissions can certainly be realized.

Figure 12 shows a conservative estimate for possible reductions in the new vehicle fleet by 2020. In fact, the measures outlined affect the long-haul segment most, due to driving and vehicle (truck and trailer) characteristics. Their potential is limited in the intercity truck segment, and very limited for urban applications. Driving conditions in both segments (with lower speeds and more frequent start-stop maneuvers) prevent improved aerodynamic or low rolling resistance properties from working efficiently. In urban traffic contexts, other improvements such as electric power take-offs and the selective use of lightweight materials will have a greater impact.

Figure 12: Potential reduction in CO_2 emissions due to vehicle improvements

Potential average reduction in new vehicle fleet CO_2 emissions by 2020 [%]



1) In some regions, modification of homologation rules needed to facilitate better aerodynamics
2) E.g. electric APUs and PTOs, weight reduction

Source: Company information; ACEA; Rocky Mountain Institute; press clippings; interviews; Roland Berger

Aerodynamics:

> Aerodynamics are an important aspect of tractors and semitrailers. OEMs have already made considerable efforts to improve tractor trucks, for instance by optimizing cab design. A concept that demonstrates the vast potential of aerodynamics was revealed at the 2010 IAA Commercial Vehicles – MAN claims that its Concept S tractor truck would allow for 25% less CO_2 emissions solely due to an optimized aerodynamic design. However, existing potential cannot yet be fully exploited in all regions. Conventional designs with the engine in front of the driver cab (typically used in NAFTA markets) have an air drag coefficient that is about 0.05 points better than that of cab-over-engine (COE) vehicles (typically used in Europe and Japan).[4] This superiority leads to a reduction in fuel consumption of at least 3%. These regional differences in truck tractor design are basically the result of regulation. In Europe, for instance,

4) Linus Hjelm/Björn Bergvist – "European Truck Aerodynamics"

the overall length of the vehicle is strictly limited by law, so that only a COE design allows for maximization of cargo space. Regulatory changes are needed here to allow for optimal realization of CO_2 reduction potential through vehicle improvements

> With semitrailers, huge gains can be realized within existing vehicle norms by using side skirts, for instance. More substantial improvements – reductions in fuel consumption of up to 20% in some cases[5] – can be achieved only if more aerodynamic trailer forms are used, such as teardrop trailers with rear spoilers. If such applications are suitable for the paticular region (bearing in mind infrastructure limitations, for example), once again the current regulations governing maximum length and height should be modified to exploit existing potential to the full. Close collaboration between vehicle and trailer manufacturers is also necessary to ensure an overall design concept that reduces air drag as much as possible

Rolling resistance/weight reduction:

> State-of-the-art tires already deliver substantial reduction in rolling resistance. Especially emerging markets such as India are lagging far behind in this regard. New tires, currently in development, promise to maintain similar grip and lifetime characteristics to those of existing tires while coping with a higher maximum load per tire. This would make it possible to reduce the number of axles needed to carry a similar load and thus reduce the rolling friction. New vehicle concepts with a maximum GVW of 38 tons (and only two trailer axles) are currently under discussion. If these endeavors find their way into volume production at a competitive price, significant reductions in rolling resistance could be realized

> One further way is to reduce overall vehicle weight. Trailer manufacturers are working hard to develop lightweight architectures that will make it possible to increase payloads. The cost of these materials is often too high to support a positive TCO, however. In Europe, Denmark, the Netherlands, Norway, Sweden and Finland have already found a workaround for this issue: increasing the maximum permissible vehicle weight and length. Indeed, 25-meter vehicles with a combined weight of 60 tons have been traveling on Finnish and Swedish roads since as far back as 1970. Other European countries have now launched trial programs taking similar steps. Two of these "EuroCombi" megatrucks would be able to carry the same load as three conventional 40-ton trucks today, reducing overall fuel consumption accordingly. The legalization of megatrucks is by no means uncontroversial, however. Organizations such as Germany's ADAC automobile club have voiced concerns about the increased wear on roads, bridges and tunnels, the lack of parking facilities for such trucks on highways and safety problems in the event of accidents. Perhaps more signifi-

5) "Shell LKW-Studie", April 2010

cantly, governments are also afraid of encouraging cargo transportation to shift from rail to road if 60-ton trucks get the green light – potentially leading to greater traffic congestion on highways and lower operating margins for what are often state-owned railway operators. Nevertheless, EuroCombi vehicles deployed on specific routes must be considered a tried-and-tested way to reduce truck CO_2 emissions

As regards financial benefits for customers, many of the vehicle improvements available today yield considerable fuel savings. The small initial investment thus has a short payback period – less than two years in many cases. A sample calculation shows that a package including an uncoupled auxiliary power unit, low resistance tires and side skirts can cut diesel costs by as much as EUR 6,000 per annum, depending on annual mileage (see figure 13). However, it is difficult to verify improvements in fuel consumption individually due to the large number of factors influencing fuel consumption (e.g. driver behavior). As a result, customers are still unsure about the real benefits and we have yet to see widespread introduction of the new technology.

Figure 13: Payback on vehicle improvement packages – Example: Canada

Payback on vehicle improvement packages – Example: Long-haul truck in Canada

	Package	Fuel consumption savings[2]	Initial investment [EUR][3]	Payback
BASIC	Side skirts (aerodynamics) Low-resistance dual tires Diesel APU[1]	~12% (~6,100 EUR/p.a.)	~9,700	< 2 years
FULL	Tractor aerodynamically improved, side skirts, base flaps, gap fairings Super single tires Battery-powered electric APU[1]	~18% (~9,500 EUR/p.a.)	~26,100	< 3 years

1) Auxiliary power unit for e.g. conditioning during driving breaks
2) Assumed mileage: 160,000 km/p.a., 33 l/100 km, 1,400 idling hours/p.a., 3.5 l/idling hour, 0.76 EUR/l diesel
3) Exchange rate CAD/EUR = 0.78/1

Source: Rocky Mountain Institute; Oanda; Government of Canada

2.4. Hybrid vehicles

Hybrid vehicles combine two or more distinct propulsion systems. In the most common type, referred to as **hybrid electric vehicles** (HEVs), a conventional internal combustion engine is combined with one or more electric motors that typically work with electricity stored in a battery. Hybrid vehicles reduce fuel consumption in two ways. First, they optimize the operating point in combustion engines with a view to minimizing fuel consumption. Second, they store the energy generated during braking and then use it to power the vehicle when needed.

Hydraulic hybrid engines are another type of hybrid technology typically used in commercial vehicles. Hydraulic hybrids use pressurized fluid (instead of electric power) as an additional source of power for the combustion engine. One advantage of this technology is that it can store and generate traction energy very quickly in stop-and-go traffic. Hybrid electric vehicles, on the other hand, still need expensive supercapacitor systems to achieve similar performance levels. The drawback with hydraulic systems is that they require large, heavy tanks to store enough energy and cannot provide an auxiliary power source from the vehicle in the way that batteries do. As a result, they are suitable mainly for applications in which vehicles repeatedly brake and accelerate sharply, such as refuse collection. Since this technology is not expected to play a major role in volume segments, we focus below exclusively on HEVs.

In terms of **system design**, two main architectures are used in commercial vehicles: **serial hybrids** and parallel hybrids. In serial hybrids, the combustion engine has no mechanical connection to the driving gear. Instead, an energy converter is linked directly to the combustion engine and recharges the vehicle's battery as required. The vehicle is therefore driven solely by the electric motor. Given a large enough battery, this architecture supports long ranges in zero-emission mode. It is best suited to vehicles such as city buses that operate in densely populated areas and on fixed routes.

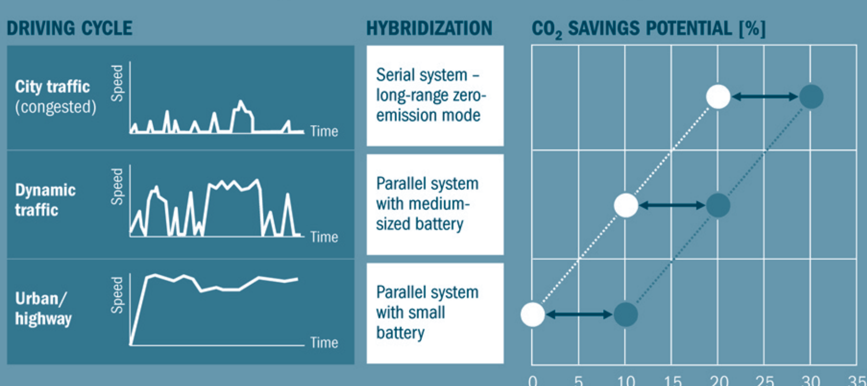
In **parallel hybrids**, the combustion engine and electric motor are both mechanically attached to the wheels and can therefore be used simultaneously. This architecture is suitable for applications where zero-emission driving is either not required or not possible (e.g. due to long distances between charging points). Compared to serial hybrids, parallel hybrids have the advantage of being much less expensive as they do not require a large battery.

Regarding hybrid systems for commercial vehicles, the industry believes it is on the cusp of one of the greatest innovation leaps ever. "There is a spirit of fresh optimism; we are in fact facing a technological sea change," MAN CEO Georg Pachta-Reyhofen recently announced in an interview.

Hybrid electric vehicles are expected to significantly reduce vehicle CO_2 emissions – some manufacturers claim by up to 30%, depending on the specific commercial vehicle segment (see figure 14). Since the most significant gains are made during starting and stopping, the vehicle's driving cycle has a huge impact on system efficiency. More extensive (and expensive) hybridization tends to happen in vehicle segments that operate in congested urban areas, e.g. city buses. In vehicle segments that involve a significant share of highway driving time, systems that focus on optimizing the combustion engine operating point are adequate. In recent press releases, OEMs claim to have achieved fuel consumption reductions of 5-10% using parallel systems with small batteries in heavy-duty vehicles, including long-haul applications. Scania, for instance, is actively developing parallel hybrid applications in the heavy-duty segment, not only for city buses and delivery trucks, but also for long-haul applications.

Figure 14: Potential for HEVs to reduce CO_2 emissions as a function of the driving cycle

Potential for HEVs to reduce CO_2 emissions as a function of the driving cycle



Source: Company information; interviews; press clippings; Roland Berger

On top of the fuel saved on the road, further optimization potential can also be tapped by using hybrid electric systems for power take-off applications such as in cranes and concrete mixers.

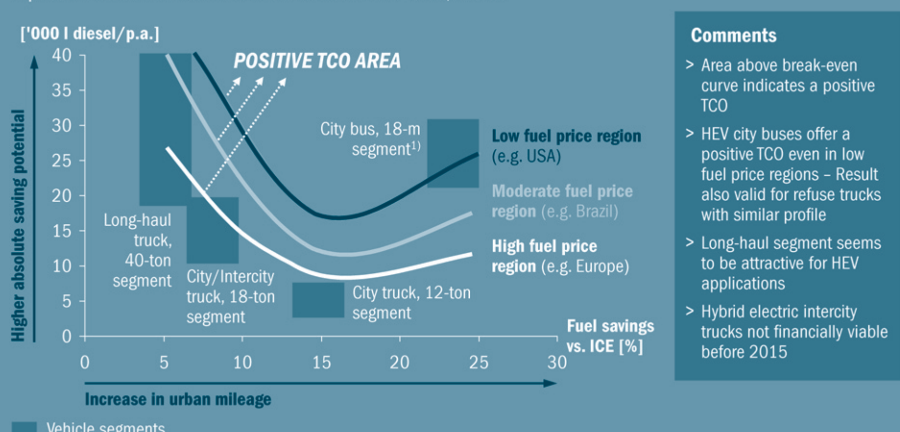
The American Hybrid Truck User Forum has tested more than 24 bucket trucks equipped with cranes driven by electric PTOs with the aim of minimizing idling time. In several cases, overall fuel consumption was reduced by an extra 20%.

Some hybrid electric vehicles are already on the market in Japan (e.g. the Mitsubishi Fuso Canter Eco Hybrid, the Hino 714 Hybrid) and the US (e.g. Peterbilt's complete range of medium- and heavy-duty HEV trucks for various applications). Sales are still very limited, however. So if hybrids can sharply reduce fuel consumption and are available on the market, what keeps HEVs from conquering the roads? Essentially, there is just one reason today: system costs.

System costs will probably remain an issue in the medium term. Figure 15 shows the expected break-even curves for HEVs as a function of urban mileage and fuel prices in 2015. For the next few years at least, HEV systems are only expected to be economically viable (given TCO considerations and assuming that there are no incentives for HEVs) in specific vehicle applications such as city buses, and mainly in countries where diesel is heavily taxed. Moreover, a positive TCO is only possible for HEV city buses after at least five years' service. The initial investment required for hybrid systems simply cannot always be recouped by the savings on fuel consumption.

Figure 15: Projected TCO break-even curves for HEV and ICE vehicles, 2015

Expected TCO break-even curve for HEVs and ICEs, 2015



1) Serial system with higher initial cost increase (higher break-even point) than parallel system assumed for all other segments

Source: Lastauto Omnibus; Dekra; Roland Berger

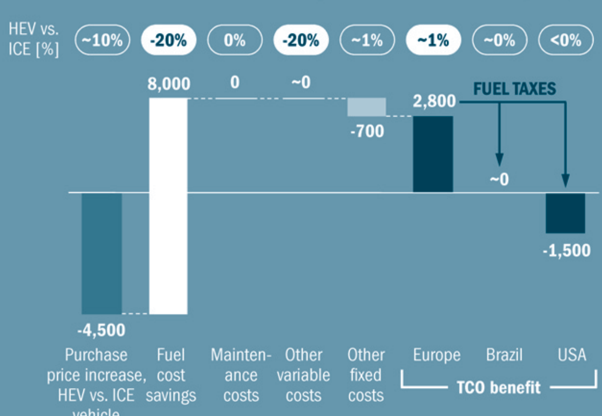
Ultimately, the underlying issue is that unit costs are still too high as a critical volume of hybrids has not yet been reached. Scania, for instance, works on the assumption that its parallel system adds between EUR 10,000 and EUR 15,000 to the price of every heavy-duty truck. Other estimates are higher, ranging from an additional 20-40% of the vehicle price.

This could all change by 2020. Synergies from battery technologies (e.g. in cell production) that can be shared with passenger cars and higher production volumes for HEV systems could slash the cost of hybrid systems by as much as 50%. If we accept this aggressive costing assumption and postulate a 4% annual increase in the price of diesel, the payback on HEV city buses could be under three years, even in regions with moderate fuel prices such as China.

As figure 16 shows, an attractive TCO is unlikely to be feasible in the medium-duty city truck segment, despite potential savings of 20%. This is mainly due to the limited annual mileage that is characteristic of urban cycles. By contrast, HEVs are expected to deliver substantial benefits for long-haul vehicles that clock up mileages of over 80,000 km per annum, despite the fact that potential savings fall below 10% in this case. By 2020, HEVs deployed in long-haul applications could likewise achieve payback within three years if synergies can be realized across segments. Of course, a sufficient decrease of system costs is essential in this regard.

Figure 16: TCO calculation for HEV and ICE vehicles in the 12-ton city truck segment, 2020

Simplified TCO calc., HEV vs. ICE city truck, 12 ton (2020) [EUR]



Comments

- Lifetime of **6 years**, starting in 2020 with mileage of **25,000 km p.a.**
- Average fuel consumption of **16.6 l/100km** assumed (reduction of 0.5% p.a. through 2020 due to ICE powertrain improvements)
- Lifecycle cost increase of 2% p.a., Brent barrel cost increase of 4% p.a. and interest rate of 7% assumed
- Hybrid system: **4 kWh** battery (power cells), **60 kW** electric motor

Source: Company information; interviews; press clippings; Roland Berger

Peak system power is put at roughly 60 kW for a medium-duty delivery application and 90 kW for a long-haul truck (example: Eaton Corp.). Here too, it should be possible to exploit major synergies regarding battery cooling and power electronics. On the other hand, if system power of 150-200 kW (similar to that needed for the hydraulic retarders in service today, up to 600 kW) is required in long-haul traffic to realize an improvement of 5-10%, fewer advantages will be possible. In this case, it will be almost impossible to achieve a reasonable payback period for long-haul HEVs.

A further challenge for hybrid electric vehicles has to do with the current battery dimensions. Especially in some long-haul trucks in Europe and Japan, packaging has become a major issue as new components are added to the exhaust aftertreatment system in response to tighter emissions regulations. Current batteries are indeed so large that they cannot easily be accommodated under the chassis. The battery for the current Mitsubishi Fuso Canter Eco Hybrid model, for example, has a capacity of no more than 1.9 kWh and is almost as large as the diesel tank. Weight is another issue that is keeping battery manufacturers busy, since every extra gram of vehicle weight diminishes one of the most important purchase criteria of all: the payload. The Canter battery, for instance, weighs about 90 kg. Nonetheless, significant improvements have been achieved in this area in recent years. A new Canter E-Cell concept (full electric vehicle) currently being introduced has a battery capacity of 40 kWh. Experts are thus confident that none of these issues will hinder broad market penetration by HEVs in the future.

2.5. Electric vehicles

Electric vehicles are defined as vehicles capable of driving 150 km or more in electric mode (with zero emissions tank-to-wheel). Such vehicles have already been deployed in the medium-duty delivery segment thanks to the work of retrofitting companies (e.g. Smith Electric Vehicles). But only a few prototypes are being currently tested by the major OEMs, and even fewer electric trucks are available for purchase. One company breaking the mold is Navistar, which has signed an alliance with Modec, a small UK manufacturer, to produce and sell small electric delivery vehicles with a gross vehicle weight of 5.5 tons in the United States.

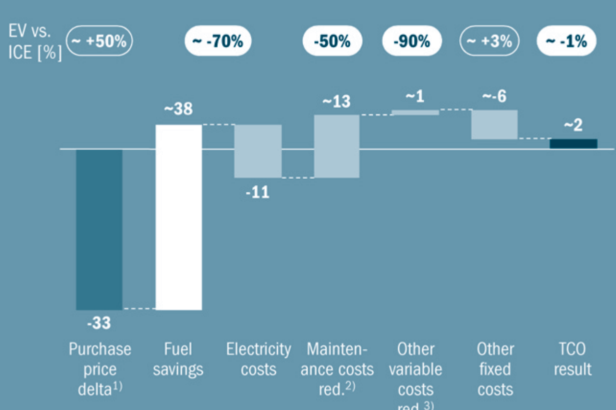
A major limitation of electric vehicles is the maximum distance they can cover before the battery has to be plugged in and recharged. Assuming average consumption of 1.7 kWh per km (e.g. for a Daimler 40-ton truck driving from Stuttgart to Hamburg), a long-haul truck would today need a battery weighing over six tons to drive 500 km in one go.

Moreover, it would take almost six days to fully recharge using a standard 220V power plug. Even with the quick charge system of the Tesla Roadster sports car, recharging would still take around two days. So even if one subscribes to the most upbeat assumptions about technological development, electric vehicles are unlikely to be a feasible option for long-haul or intercity applications. They are quite simply far better suited to applications where the distance between charging points (or battery swap points) is relatively small, as in the case of urban cycles. City bus fleets are a case in point: the routes are known in advance, buses are parked only in a limited number of places, and fleets normally include a limited number of different vehicle models. Thus it might be possible to create operating models not only with recharging points along the daily route, but also with battery swap points for quickly replacing empty batteries with fully charged ones, or to move to inductive charging (standard solution e.g. for forklifts). These facts are already attracting the interest of local authorities who want to improve air quality in their cities. For instance, a fleet of electric buses have been in use in Shanghai since 2006.

Once again, the biggest barrier to overcome is system cost. The battery is the sticking point here, since the cost of the other electric components (e.g. electric motors and power electronics) is expected to be more or less equal to the savings gained from the combustion engine components that they render superfluous.

Figure 17: TCO calculation for EV and ICE vehicles in the city truck segment, 2020

Simplified TCO calc., EV vs. ICE city truck, 12 tons (2020) in Europe [EUR '000]



Comments

- Lifetime of **6 years** – Mileage of **25,000 km p.a.**
- Higher purchase price due to **battery** (120 kWh)
- Costs for other **electric components** slightly lower than those of the ICE equipment they render superfluous
- Forecast CAGR of 4% for **electricity** and **Brent** prices
- Reduction of **maintenance** costs through more durable wear parts (e.g. brake pads) and reduced scope
- Interest of 7% assumed for other **fixed costs**

1) Including electric components (e.g. HVAC)
2) E-motors assumed to require no significant maintenance 3) E.g. lubricants

Source: Company information; interviews; press clippings; Roland Berger

Despite the cost issues, economies of scale – especially synergies with passenger car plug-in HEVs and EVs, not to mention advances in R&D – are expected to make the TCO positive for city buses by 2020, if a limited range of 150 km is accepted. Simplified TCO calculations that compare medium-duty electric city trucks with conventional trucks are very revealing: In regions with high fuel prices such as Japan and Europe, these calculations show that a positive TCO could be achieved within a six-year operating period if the cost of batteries (including energy cells) is cut by 50% compared to today, down to a level of EUR 300 per kWh.

Further challenges for EVs concern other aspects of battery technology such as safety, durability and charging speed. While experts say that these issues will be resolved shortly, conclusive evidence is lacking as lithium-ion technology for automotive applications is still in its early days.

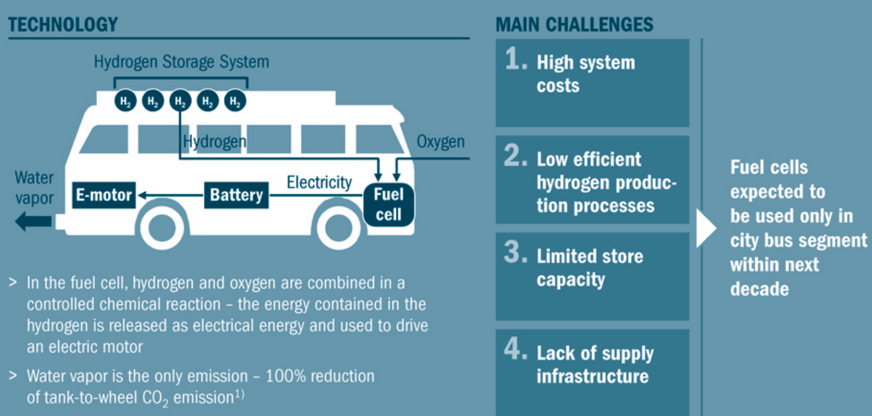
2.6. Fuel cells

Hydrogen fuel cells do not give off any tank-to-wheel CO_2 emissions: the overall potential for carbon reduction depends on the method used to produce the hydrogen. Where hydrogen is generated from wind power, for example, overall well-to-wheel CO_2 emissions can be reduced to almost zero. Moreover, fuel cells can operate virtually endlessly as long as the necessary replenishment flows are maintained.

The vision of zero-emission driving has led several major cities to carry out field tests for city buses, even though the cost of such prototypes is still extremely high. For instance, a fleet of over 30 fuel-cell buses from Mercedes-Benz is currently up and running in ten major European cities, plus Perth in Australia and Beijing in China.

Yet of all the alternative technologies we have examined, fuel cells seem the least advanced option for powertrains at present. Many OEMs are currently testing fuel cells for passenger cars and city buses, but very little practical experience of this technology has yet been accumulated. Sustainable solutions for producing hydrogen are expensive: producing one liter of conventional diesel costs about EUR 0.40, while producing the hydrogen equivalent currently costs more than EUR 2.00. Compressing and liquefying hydrogen also incurs high energy costs. Restricted storage capacity too poses technological challenges as it limits vehicle driving ranges. Moreover, fuel cell systems require a significant maintenance effort and efficiency decreases as load increases. Both factors make them rather unsuitable for medium- and heavy truck applications. All in all, as with the other technologies investigated, the overall system costs remain high.

Figure 18: Challenges and expectations regarding the application of fuel-cell vehicles



1) Tank-to-wheel analysis; CO_2 emissions generated during fuel production are not included

Source: Roland Berger

Finally, another major disadvantage with fuel cells is the fact that, as things stand, the necessary hydrogen supply infrastructure is virtually non-existent. This will remain an issue at least for the next 10 years, both for passenger cars and for trucks. The few filling stations there are remain confined to major cities. Making hydrogen available on a large scale would require huge investments and would need to be planned from scratch. City fleets, however, could resolve this dilemma by installing a few filling stations at the garages where vehicles are parked overnight.

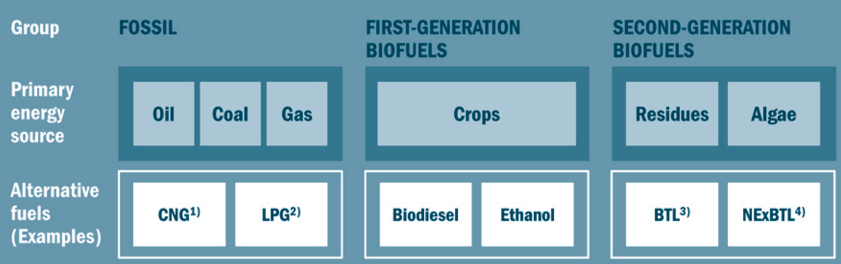
Clearly, hydrogen faces not only technological but also production, distribution and maintenance challenges. It is thus highly unlikely that fuel cells will be used for any commercial vehicle segment other than city buses in the next decade. At the same time, anticipated advances in electric vehicle technology could undermine local authorities' interest in city buses fitted with fuel cells, thereby hindering widespread introduction even in this segment.

2.7. Alternative fuels

Alternative fuels can be classified in three different groups depending on the primary energy source (see figure 19). Alternative fossil fuels are gasiform crude oil derivatives that are pressurized to keep them liquid.

They are usually generated as by-products of the crude oil extraction process. First-generation biofuels are primarily produced from food crops such as grain, sugar beet and oil seeds. Second-generation biofuels are produced from non-food biomass such as wheat straw, various grasses and wood.

Figure 19: Different types of alternative fuels



1) Compressed natural gas 2) Liquid petroleum gas 3) Biomass-to-liquid 4) Refined from vegetable oil
Source: Roland Berger

Alternative fossil fuels

These types of fuels can significantly reduce CO_2 emissions. If it could run on compressed natural gas (CNG), a diesel engine would generate approximately 25% fewer emissions than with diesel. Unfortunately, alternative fossil fuels do not auto-ignite in diesel engines, as they would need to do. Instead, combustion cycles involving lower efficiency have to be used to burn alternative fossil fuels. The resultant inevitable increase in fuel consumption limits the reduction of CO_2 emissions to approximately 6%.

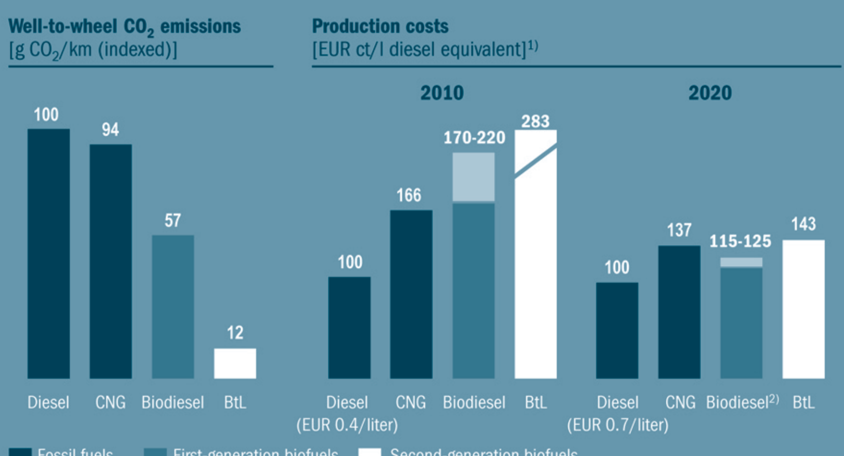
There are other problems too. Since alternative fossil fuels are inherently limited, they meet the political need to cap CO_2 emissions but do little to solve the wider problem. Some alternative fuels such as CNG/LPG could benefit from the existing diesel distribution network, but alterations to filling stations are unavoidable. Due to the need for engine modifications and special storage systems, vehicles that run on these fuels are more expensive than vehicles fitted with standard combustion engines. The maximum capacity of CNG/LPG storage tanks (and hence the maximum vehicle range) is also problematic. The Mercedes-Benz Econic 1828 NGT, for example, can cover 450 km with a full tank, according to company information – 57% less than the 1,050 km its combustion engine counterpart can manage. Still, gas engines are one development path that is currently being exploited by Chinese truck manufacturers, for instance.

Recent developments show that blending natural gas with diesel may, after years of development, become an interesting alternative to conventional diesel, as such mixtures can work with highly efficient diesel engines without the need for modification. A number of issues remain to be solved regarding compliance with future emission norms such as Euro VI and how CNG is taxed. Assuming that this technology reaches volume readiness, it is logical to expect natural gas prices on the market to rise sharply. This in turn would have enormous repercussions for other stakeholders such as utilities and households. Even governments would be affected, as they would have to find a way to compensate the tax losses caused by lower diesel sales.

First-generation biofuels (biodiesel)

Biodiesel can reduce CO_2 emissions by approximately 40%, provided a 100% biodiesel blend is used. First-generation biofuels are produced from renewable biomass. Although OEMs need to make additional engine modifications to avoid problems with sealings, hoses and filters, first-generation biofuels could certainly make use of the existing filling station infrastructure and would therefore require no major investments on this score. However, their usage will always be restricted by the limited availability of agricultural land and the resultant competition with food crops. As the world population is growing all the time, this option appears destined to remain problematic from a political perspective.

Figure 20: Comparison of alternative fuels and regular diesel



1) For Diesel: 37.4 MJ/l assumed 2) EUR 60-80/ton dry mass NOTE: CNG considered on the basis of a combustion cycle

Source: VDA; FNR; IEA; MAN

More important than all the other issues, however, is the fact that, barring government incentives, first-generation biofuels are not expected to be cheaper than diesel even after 2015 in Europe. Accordingly, customers are unlikely to ever use pure (100%) biodiesel as a preferred fuel. In Germany, for instance, sales of pure biodiesel have gone down by over 85%[6)] since the announcement in 2006 that taxation on biodiesel would be increased to the level of regular diesel. Looking further ahead, it is assumed that after 2020 first-generation biofuels will in any case play no more than a minor role. The outlook is that these fuels will be replaced by alternative feedstocks and processing technologies such as lignocellulosic biomass, the biomass-to-liquid (BTL) process, algae, and so on, gradually giving second-generation biofuels pride of place.

Second-generation biofuels

Second-generation biofuels have substantial potential to reduce CO_2 emissions and are expected to solve many of first-generation biofuels' problems relating to food usage. On the downside, they will not be technically viable on a mass scale for another five to ten years. Production capabilities must also be built up from scratch. In view of the huge investment this will necessitate, it is not reasonable to assume that these fuels will be economically viable before 2020. Second-generation biofuel targets have already been set in the US, however, where 60 billion liters have to be created by 2022. Similar decisions are expected in some European countries. If initiatives like these gain momentum, funds and efforts could well be redirected toward second-generation biofuels, thereby speeding up the overall advancement of related technologies.

On top of today's compulsory blends (e.g. the minimum of 4.4% biodiesel in Germany), an additional 5-10% of global gasoline and diesel demand could be substituted once second-generation biofuels reach their full potential. In theory, this will be when between 10% and 25% of the world's agricultural and forestry residue is used to produce them. Assuming that this potential will not be fully developed by 2020, and considering the reduction level of first- and second-generation biofuels, these blends would mean a CO_2 emissions reduction of 5-8% in the triad markets compared to scenarios in which conventional diesel is the only fuel used. In markets such as Brazil, where the alternative fuel industry is already strong, further contributions can be expected as the compulsory admixture of biofuels to diesel is stepped up.

6) German Federal Office of Economics and Export Control

2.8. Summary

In theory, a number of technologies could be used to reduce CO_2 emissions from commercial vehicles. No one technology alone will be able to achieve the reductions governments are expected to demand for new vehicles by 2020. All the options involve significant challenges that will have to be overcome in the years ahead, ranging from reducing system costs and amending current regulations to achieving substantial gains in technological efficiency.

It is not enough to look at the technologies in isolation: OEMs and suppliers must consider the varying conditions that prevail in different regions. Bearing in mind the particular situation with regard to existing fleets, average consumption levels and customer purchase criteria, industry players need to develop specific strategies for each region.

3. Market characteristics: How will market requirements influence the development of low CO_2 emission technologies?

3.1. The triad markets

The triad countries differ in many ways. The US uses conventional vehicle architectures, for example, while Europe and Japan use cab-over-engine truck designs. But the different markets are all fairly similar when it comes to CO_2 issues:

> All three regions are very much dependent on oil imports to satisfy domestic demand for diesel and are interested in reducing diesel consumption in their existing fleets

> All three have strict emissions standards with similar maximum thresholds for exhaust emissions, which have driven advances in exhaust aftertreatment technology

> The efficiency of combustion engines and vehicles in general has reached an advanced level in all the triad markets, in line with the globalization strategy adopted by most triad-based OEMs in recent years. As a consequence, the conventional ICE powertrain improvement potential for new vehicles in different segments is similar throughout the triad markets

> Thanks to professional fleet management, vehicle fleets are relatively new and have few "thirsty" old vehicles. The average age of vehicles in Germany's long-haul fleet is estimated at 8.1 years, for example.[7] Thus new technologies tend to penetrate the triad markets quite rapidly

The relevant market drivers in the triad regions are also similar:

> All three regions have mature markets with moderate sales growth expected in the coming years compared to the pre-crisis year 2007 (~21% sales growth to 2020 in the US, for example, compared to over 50% growth worldwide)

> Triad customers pay great attention to TCO and commonly have access to financial services. It follows that higher costs due to innovation do not usually constitute a major hurdle, provided there is a reasonable payback period. Having said that, the maximum period within which customers expect a payback is much shorter than the vehicle lifetime.

7) German Federal Motor Transport Authority

A Roland Berger survey conducted among freight forwarding companies in Germany recently found that the expected payback period is generally between one and four years

> "Green credentials" are increasingly becoming a powerful purchasing criterion in the triad markets due to growing public pressure, environmental awareness and transparency across the value chain

> Japan has already enforced some fuel efficiency targets for commercial vehicles, and the US and Europe are expected to follow suit. Various incentives and penalties have been put in place to help alternative powertrain technologies and alternative fuels penetrate the market

A common picture emerges for the triad markets regarding the technology mix that could ultimately lower CO_2 emissions in the different vehicle segments. Figure 21 shows the expected best-case and worst-case potential for reducing new vehicle fleet CO_2 emissions in the triad markets, i.e. the minimum and maximum potential reduction in CO_2 emissions from improving the technology in vehicles powered at least partially by combustion engines. Electric and fuel-cell vehicles have no tank-to-wheel emissions and are therefore not shown in the figure.

Even under best-case conditions, it is clear that significant numbers of hybrid electric vehicles are needed if the proposal to reduce CO_2 emissions by at least 25% is to be met by 2020 in the triad markets. In the city truck segment, for instance, the remaining gap of at least 6% (given that improvements to internal combustion engines and the use of alternative fuels will together reduce carbon emissions by around 19% at most) needs to be closed by a combination of HEVs, EVs and fuel-cell vehicles. Assuming that electric and fuel-cell vehicles will play only a minor role between now and 2020, however, and that the average reduction in fuel consumption in the new vehicle fleet will equal the 20% maximum expected from hybrid technology in this segment, market penetration within the new fleet would have to be around 30%.

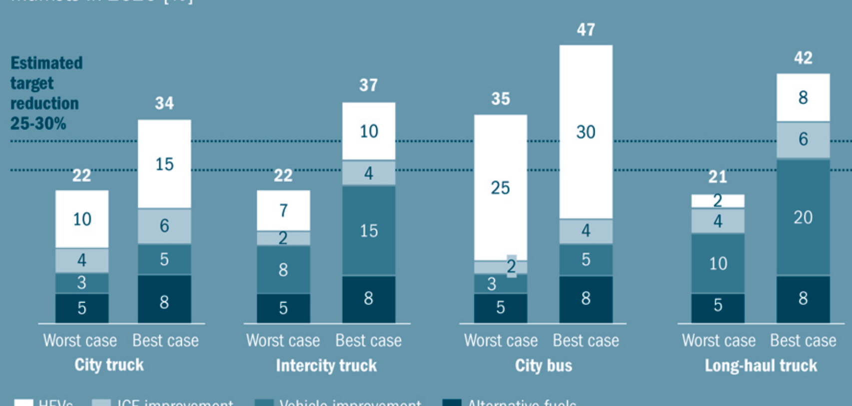
Of course, a high level of market penetration will only come about if a positive TCO case can be clearly demonstrated. Even with aggressive assumptions about reductions in system costs, this is rather a tall order at present. Incentives and penalties will thus play a key role in driving the widespread introduction of HEVs on the market.

A similar situation can be observed in the intercity truck segment. Even after leveraging all possible improvements, HEVs will still be needed to close the gap. The operating conditions may facilitate payback within the vehicle's lifetime. Even so, given customers' payback expectations, incentives and penalties may be needed here too to fuel the introduction of HEVs.

Could CO_2 emissions be reduced by upward of 25% (as in figure 21) merely by concentrating on HEVs and not supporting the further development of expensive alternative fuels? Here, it is important to remember that alternative fuels impact not only new vehicles, but the entire fleet of existing vehicles. The estimated target of reducing carbon emissions by 25-30% for the new vehicle fleet is based on the assumption that alternative fuels will contribute a reduction of at least 6% by 2020. Without this effect, the new vehicle fleet would naturally have to provide a higher total reduction to make up the difference.

Figure 21: Estimated worst-case/best-case potential for CO_2 emissions reduction by segment in the triad markets in 2020

Estimated potential to reducing average new vehicle fleet CO_2 emissions by segment in the triad markets in 2020 [%]



Source: Company information; interviews; press clippings; Roland Berger

City buses will also need hybrid technology if they are to reduce their CO_2 emissions by more than 25%. A positive TCO case and lower battery costs will, however, soon pave the way for large-scale market penetration. Given that many incentive programs supported by local authorities are promoting

HEVs in this segment, market shares of over 50% in revenue terms could be feasible in the triad markets by 2020. Moreover, depending on the trend in fuel and battery prices, electric vehicles may even be able to establish themselves in this segment by 2020. Other vehicles designed for similar applications and commissioned by local authorities – refuse trucks, for example – will plot a trajectory similar to that of city buses.

In the long-haul segment, the legislation needed to enable maximum efficiency through vehicle improvements, such as anti-idling laws and increased maximum size and weight of vehicles, could be enough to achieve a sufficient reduction. But hybrid electric vehicles could also play a role in this segment, for two reasons. First, synergies with the intercity truck segment (where HEVs are also vital if CO_2 targets are to be met) could mean a broader volume base enabling OEMs to amortize their development costs. Second, given the mileage clocked up in this segment (generally more than 100,000 km p.a.), a positive TCO could be realized before 2020 even in countries such as the United States where tax on diesel is low.

3.2. Emerging markets

As far as CO_2 emissions are concerned, there are few similarities between emerging markets and the triad markets at the present time. Dependency on oil imports to satisfy demand is the only key issue on which emerging markets often face the same challenges as their triad peers.

Significant differences exist with regard to fuel consumption levels (see section 2.3) and the age of vehicle fleets. Replacement rates in emerging markets are especially low in both rural areas and urban regions outside major cities, so aging vehicles account for a considerable share of these markets. Figure 22 shows the structure of the Brazilian truck fleet as a function of the emissions regulations with which the vehicles comply. An estimated 60% of the existing fleet does not even comply with the Euro I emissions norm, introduced in Europe in 1992, whereas new trucks are already Euro III-compliant. In terms of laws and regulations governing vehicle emissions, emerging countries are also often at least five years behind the triad markets.

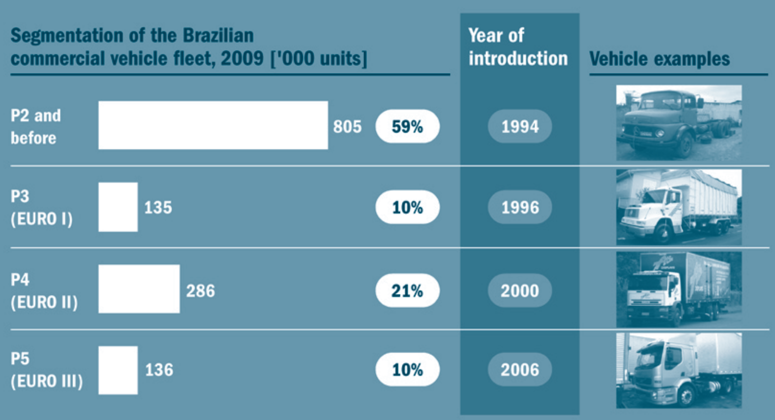
There are clear signs that market drivers are converging globally across the triad and BRIC markets. Nevertheless, a number of obvious differences persist:

> Substantial sales growth through 2020 (growth of over 80% compared to 2007 in China, for example) will make it easier for new technologies to penetrate the market

> The level of driver training, fleet management and so on is generally not as advanced as in the triad markets. Customers are often rather indifferent toward new powertrain technologies. Moreover, purchase price is still one of the main purchase criteria and customers pay less attention to TCO

> Most emerging countries have yet to engage in any in-depth discussion of CO_2 emissions reduction targets for commercial vehicles. But deteriorating air quality in heavily populated areas has become a major issue. This fact, plus the recognized need to limit global warming, is driving authorities to implement tougher emissions standards similar to those of the triad markets. CO_2 emissions reduction targets are expected in many emerging countries by 2020, and some countries are already taking initial steps. In Brazil, the compulsory admixture of biofuels to diesel was raised to 5% in January 2010. The Brazilian government intends to gradually increase the prescribed admixture to 20% by 2015, depending on the region. In China, several local initiatives have been launched to promote the development of alternative powertrains, such as the hybridization of city bus fleets, thereby assisting local OEMs as they compete with triad-based OEMs

Figure 22: Segmentation of the Brazilian truck fleet by emission standard



Source: ANTT (National road transportation agency); CNT (National Transportation Confederation)

In emerging markets, the significant reductions in fuel consumption discussed in section 2 could be achieved by introducing some of the proven vehicle and powertrain technologies already available in the triad markets. Several barriers remain to be overcome, of course – one obvious one being the need to encourage owners to take a more professional view of TCO rather than focusing on the purchase price. Even so, it is reasonable to expect that, as markets continue to develop, these technologies will gradually permeate emerging countries too.

At the same time, supporting the renewal of old vehicles would be a tremendous help in cutting overall CO_2 emissions. Vehicles sold in Europe 15 years before the Euro III standard was introduced in 2001 had average consumption levels approximately 15% higher than those of their Euro III-compliant counterparts[8)]. Once again, the major barrier here is the fact that owners attach too little importance to TCO. Governments and market players will need to develop effective strategies to nudge significant numbers of customers in the direction of new trucks with low CO_2 emissions.

Although existing technologies can – and will – significantly impact fuel consumption in emerging markets, some governments and market players have already identified clear opportunities for narrowing the technological gap by promoting alternative powertrains. In countries such as China and elsewhere, hybrid electric vehicles will gain significant market shares between now and 2020, although they will fall short of those expected for the triad markets. Even in countries such as Brazil that are blessed with large deposits of natural resources and have elected to back the development of a strong alternative fuel industry, HEVs will probably be introduced by the local partners of triad-based OEMs.

Especially in segments where a clear case can be made for a positive TCO, HEVs can be expected to gain a significant market share by 2020. The main driver of this development will be the aim of achieving economies of scale so as to reduce system costs.

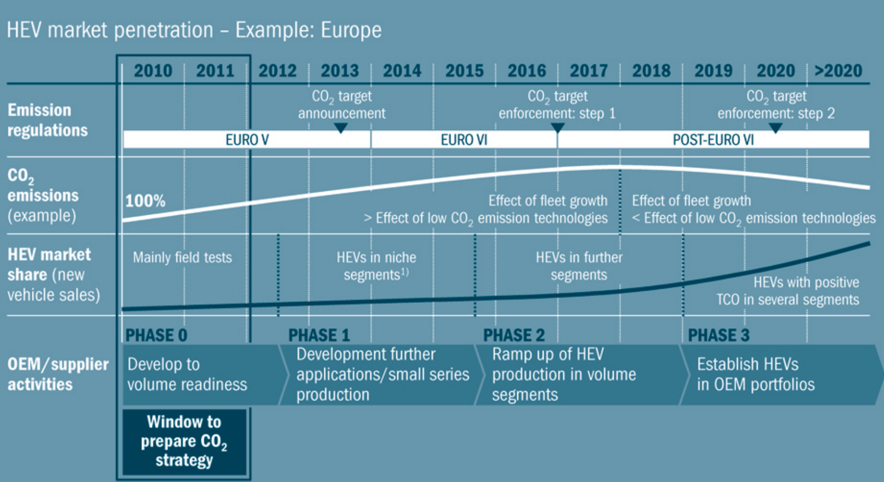
8) Engine-, transmission-, axle-technology as well as tires and road condition also contribute to this effect

4. Consequences and options: What must market players do now to master the challenges ahead?

4.1. Need for action in the triad markets

As we saw in section 3.1, the triad markets have no alternative but to introduce large volumes of hybrid vehicles if expected CO_2 emissions reductions up to 30% are to be met. And this needs to happen quickly. Taking Europe as an example, figure 23 shows one possible scenario regarding the enforcement of reduction targets. Governments, vehicle manufacturers and system suppliers alike must act quickly to ensure they get the required volume of HEVs to market by 2020. We divide the steps they need to take into four phases.

Figure 23: One possible scenario for HEV introduction in Europe



1) E.g. city buses and refuse trucks (positive TCO compared to vehicles powered by ICEs)

Source: Roland Berger

The first phase is the most critical. Decisions taken here will chart the course by which lower carbon emissions are to be achieved. All the strategic work must be accomplished in this phase. In the subsequent phases, market players and governments will essentially have to focus on implementing the strategies defined at the outset. Governments in the triad markets must take the following actions:

> Define suitable **methods for measuring CO_2 emissions** for commercial vehicles in collaboration with OEMs and suppliers. Here, it is important to consider all factors influencing emissions. The University of Graz, for instance, is currently developing such method for the European Commission. Another related and critical issue is the need to align standards on a global level to enable scale effects to be realized within regions

> **Set transparent CO_2 emissions reduction targets** as soon as possible. This will give the industry a clear framework to work in. The targets must be ambitious, but at the same time they must be realistic enough to guarantee a smooth transition period for market players. In addition, regulations should avoid creating distortions that could encourage inefficient shifts between vehicle segments, e.g. dividing the load currently carried by one heavy-duty truck into several medium-duty truckloads in order to comply with limits, which would ultimately push CO_2 emissions per ton and km up rather than down

> **Modify regulations** to enable maximum efficiency to be derived from existing standard technologies such as aerodynamics, as discussed in section 2.3

> **Draw up an overall strategy** creating incentives for the introduction of alternative technologies in line with the emission reduction targets. This point will be crucial given that many forthcoming improvements will not pay for themselves by 2020 in a way that would ensure broad market penetration. The strategy must therefore embrace aspects that support both the supply and demand sides (see section 1)

For their part, vehicle manufacturers and system suppliers face a dilemma. On the one hand, they have no choice but to go hybrid. On the other hand, they must master the resultant technological complexity and start producing in sufficiently high volumes to reduce costs. Additionally, they must divide their attention between overall vehicle improvements and the need to improve powertrains in vehicles fitted with combustion engines.

On an operational level, the first hybrid applications should be developed for vehicle segments where a positive TCO can be realized fastest. This is the best way for manufacturers to gain experience of the system quickly while ensuring that customers get an attractive deal even in the early years of alternative powertrains for commercial vehicles.

A further critical step in this first phase is for OEMs and suppliers to formulate a comprehensive CO_2 strategy. This is imperative if the market players affected by CO_2 regulations are to succeed in the medium term. A successful strategy must include at least the following elements:

> **Plot a technology roadmap** and **redefine internal competencies** to efficiently allocate resources as a function of the vehicles and markets served

> **Define a global modular system** to realize scale effects within vehicle segments and regions

> **Establish alliances with selected OEMs or suppliers** to reduce risks and minimize R&D expenses. Paccar, for example, launched a joint venture with system supplier Eaton in 2007 to create a new line of hybrid vehicles. The joint venture is very clear about its mandate, as Mark C. Pigott, the company's Chairman and Chief Executive Officer stated: "Paccar has targeted an ambitious goal of 30% improvement in vehicle fuel efficiency for selected medium-duty applications over the next seven years, utilizing hybrid technology as a key contributor to achieving this objective." Today, Paccar's two vehicle brands in the US (Peterbilt and Kenworth) sell hybrid models catering to a wide range of applications, including heavy-duty trucks for long-haul applications

> **Collaborate with other industry players** to define global standards for the components (such as batteries) to be used in alternative technologies and thus facilitate scale effects. While passenger car manufacturers usually talk about what differentiates components such as batteries and electric motors, truck manufacturers take the view that, for commercial vehicles, tuning the various components properly is much more important. For them, standard components pose no serious threat to their brand positioning. The CO_2 challenge will also require closer collaboration, for example between truck and trailer OEMs. Emission reduction targets can be tackled more effectively by focusing on an integrated vehicle concept (adjusting truck and trailer aerodynamics so as to realize the highest possible combined emission reduction for the complete vehicle, say)

> **Map out a supply chain strategy** that can deal with potential bottlenecks, especially with regard to suppliers of raw materials. This is particularly important for electric traction machines as the most effective permanent magnet synchronous machines need a large amount of rare earth elements, most of which are mined in China

> **Prepare an effective marketing/communication strategy** for CO_2 activities to ensure that customers are informed of both ongoing activities and the benefits of new technologies. A technology will succeed on the market only if customers are convinced by the TCO. Another positive effect can be achieved by positioning the brand as a pioneer in the "green vehicle" segment. Many companies appear to be following this strategy and have established development agreements with customers to conduct field tests with hybrids. UPS, for instance, is emphasizing the company's "green culture" that is reflected in one of the largest private alternative fuel fleets in its industry. Renault Trucks has gone one step further, signing a partnership agreement with Electricité de France SA (France's biggest utility company) to develop electric trucks and commercial vehicles for goods delivery in urban areas. The aim of this partnership is to build up expertise regarding the performance of lithium-ion batteries and charging systems in this type of application

> **Plan the overhaul of sales and service networks** that will be needed to accommodate electric powertrains. Companies' employees are used to handling high-voltage applications, such as starter motors. However, focused workshops will be necessary on the new technologies reaching the market

> **Create a central position** with responsibility to oversee efforts to reduce CO_2. This position should make sure that all the relevant functions in the company are involved, and manage their activities on this front. Daimler took the first steps in this direction back in 2008, when it founded its Global Hybrid Center in Japan to bundle all group activities related to commercial vehicle hybrids

Furthermore, the chosen strategy has to resolve the issue of future competition from heavily regulated, subsidized growth markets such as China. Emerging market OEMs see electric powertrains as the perfect opportunity to narrow the technological gap between them and their triad counterparts. Thus, in the passenger car industry, Tianjin Qingyuan formed a partnership with CODA Automotive to export electric vehicles to the US, for example. Commercial vehicle manufacturers from emerging markets, backed by generous government incentive programs, are also highly likely to expand into the triad markets as soon as alternative powertrains become widespread.

Examples of market success for hybrid technology – such as the introduction of the Toyota Prius – are by no means confined to the passenger car industry. US-based commercial vehicle system supplier Eaton has adopted an aggressive strategy to establish its hybrid system on the market, and like Toyota it has been doing very well.

Pursuing a front-runner/innovator strategy, Eaton has positioned itself as a major supplier of hybrid systems, establishing strong relationships with a long list of major fleet operators, including Coca-Cola, FedEx and UPS.

These OEM customers are now asking vehicle manufacturers to collaborate with Eaton when developing hybrid trucks. As a consequence, Eaton has already developed HEV systems for DAF/Peterbilt/Kenworth, Ford, International, Iveco and Freightliner/Mercedes-Benz – manufacturers responsible for 80% of total NAFTA truck sales in 2009. The expertise Eaton has amassed has also facilitated significant penetration of the Chinese bus market, where the company has already developed or is currently developing hybrid systems for Foton, King Long, Yutong and others. In this way, Eaton has been able to capitalize on its early market entry.

4.2. Need for action in emerging markets

In emerging markets there is a general need to reduce hazardous emissions of all kinds from commercial vehicles. This can be achieved by introducing similar limits to those found in the triad markets – the EPA 10 in the US or Euro VI in Europe, for example. Since diesel will remain the dominant fuel for commercial vehicles over the coming decades, the implementation of exhaust aftertreatment systems like those used in the triad countries is essential. Governments and market players must overcome a number of hurdles. They include establishing distribution networks for the urea used in selective catalyst NOx reduction systems to comply with Euro V-VI standards, developing low-cost supply chain structures for post-Euro III powertrains and aftertreatment systems, and improving fuel quality. Improving fuel quality means, among other things, reducing the level of sulfur it contains to below 10 ppm so it can be used in post-Euro III catalysts. Brazil recently postponed the introduction of the Euro IV norm for new commercial vehicles, originally scheduled for January 2009, because the major oil corporations in Brazil and Argentina were unable to provide the required fuel quality on time.

The introduction of new standards, combined with national incentive and penalty programs to motivate the owners of old trucks to buy new vehicles, will help reduce fleet fuel consumption. In addition, emerging market players must formulate comprehensive CO_2 strategies like those found in the triad markets. Crucially, they must decide which approach to adopt: Do they want to be fast followers or front-runners?

As discussed in section 2.2, it would be possible for emerging market players to follow the path of adapting combustion engine vehicles, despite the challenges. This fast follower approach would involve gradually incorporating the improvements currently in use in the triad markets to significantly reduce CO_2 emissions between now and 2020. Concurrently, alternative powertrains can be adopted once they show themselves to be reliable and economically viable.

Given the expected gap of approximately five years between the implementation of CO_2 emissions limits in the triad markets for new vehicles and their adoption in the BRIC markets, this could be a reasonable way to minimize risk and limit upfront investment, while still meeting the anticipated limits on time.

A front-runner approach, by contrast, would enable market players to capitalize on early market entry with specific new powertrain technologies. While their reward would be a larger market share and greater brand recognition, this approach would also entail heavy upfront expenditure and investments. Government incentives and support are therefore vital. The Chinese government is following this strategy, fostering the development of alternative electric powertrains for commercial vehicles by providing incentives and subsidies (see case study below). Chinese OEMs are rising to the challenge – they are already targeting a leadership role in the passenger cars segment in developing electric vehicles. For example, 16 car manufacturers and utilities recently founded an industrial association[9)] for the development of electric vehicle businesses. One major target is to develop standards for EV components such as batteries. If they succeed in establishing a global standard, this would mark the first step toward global leadership in EV technology.

In the previous section, we discussed the need for triad-based OEMs to complement their CO_2 strategies with ways to defend themselves against the threat of emerging market manufacturers forcing their way onto triad markets. Triad-based OEMs also need to create low-cost solutions for alternative technologies if they hope to compete with local OEMs on their own territory in emerging markets. Downscaling systems developed for the triad markets will not always be enough to ensure success. Instead, triad-based OEMs must identify those technologies for which a locally developed and produced solution is vital for competitive offerings.

Considering the aggressive stance some governments are taking on alternative technologies, triad OEMs must act quickly if they want to take advantage of the expertise in low CO_2 emission technologies they have acquired in their home markets. They must leverage the alliances they have established with emerging market OEMs in order to maximize scale effects and thereby reduce system costs for their triad products.

9) Xinhua Business Weekly: "State-owned Enterprise Electric Vehicle Industry Alliance"

Case study

China aims to play a lead role in new-energy vehicles

The Chinese government recently expanded its "10 City" program from 13 to 20 cities. This move, coupled with the latest round of rules and regulations to support electrification of the powertrain, underscores how serious the government is about taking a lead role in this sector in the medium term.

The 10 City program concentrates primarily on buses and passenger vehicles. Five of the seven cities recently added clearly reflect this focus:

> In Tianjin, Tianjin Qingyuan Electric Vehicle plans to ramp up annual production capacity for electric cars to 20,000 vehicles per shift. It also plans to assemble as many as 1,000 hybrid buses a year
> Yutong Bus in Zhenzhou is focused on building electric buses in the 10- to 18-meter segment
> Higer Bus in Suzhou plans to be able to roll out 3,000 hybrid buses a year by 2015
> King Long Bus in Xiamen already ranks as one of the leading suppliers of new-energy buses
> GAC Auto in Guangzhou will supply the hybrid buses for the 16th Asian Games, while at the same time developing a pure electric city bus

China started pumping subsidies into new-energy buses last year (see figure 24). Pure electric city buses receive subsidies of more than EUR 50,000 per vehicle.

Figure 24: Examples of incentives for alternative powertrains in China

Incentives for city buses in 10 m+ segment [RMB 10,000]

			Nickel-metal hydride battery, lithium-ion battery and super-capacity hybrid	
Vehicle type	Fuel-saving rate	Lead-acid battery	Max. electric power rate: 20%-50%	Min. electric power rate: >50%
Hybrid vehicle	10-20%	5	20	–
	20-30%	7	25	30
	30-40%	8	30	36
	>40%	–	35	42
Pure EV	100%	–	–	50
Fuel-cell vehicle	100%	–	–	60

Subsidy target and amount for electric motors

		Subsidy [RMB/kW]	
PRODUCT TYPE	Rated power [kW]	1st level	2nd level
Low-voltage three-phase asynchronous motor (voltage < 690V)	0.55 ≤ power ≤ 22	40	35
	22 < power ≤ 315	20	15
High-voltage three-phase asynchronous motor	355 ≤ power ≤ 25,000	12	
PMSM motor (voltage < 690V)	0.55 ≤ power ≤ 22	60	
	22 < power ≤ 315	40	

Source: Chinese government website

The backing of central government is supplemented by local government assistance:

> By 2012, **Beijing** plans to deploy 5,000 pure electric buses and cleaning vehicles

> **Jinan** contributes an extra RMB 40,000 to the cost of every new-energy bus

A series of new campaigns and regulations, all designed to promote the roll-out of new-energy vehicles on an industrial scale, is scheduled for August 2010. On May 31, 2010, the Chinese Ministry of Finance and National Development and Reform Commission launched a new subsidy policy designed to support home-grown electric motor production. Under this policy, considerable sums are set aside for the permanent magnet synchronous machines that are so important to the truck sector. Assistance is only granted where the machines are developed, manufactured and used in China.

The following suppliers qualify for subsidies under the new policy:

> Suppliers whose annual volume exceeds 300,000 kW for three-phase asynchronous machines or 10,000 kW for permanent magnet synchronous machines

> Suppliers whose products have complied with local standards for at least three years

> Suppliers who can provide evidence of a history of relevant sales to vehicle manufacturers

Seen in light of plans to restrict exports of rare earth elements (such as the neodymium that is essential to permanent magnet synchronous machines), this policy reflects a strategy that clearly aims to boost local industry and force international suppliers to go the way of local development and production.

5. Authors/co-authors

Authors

Norbert Dressler (Stuttgart) is Partner at Roland Berger Strategy Consultants in Germany. He is responsible for the commercial vehicle, agricultural and construction vehicle cluster within Roland Berger Strategy Consultants. In his 11 years of consulting experience worldwide he has focused on the automotive OEM and OES industries. He holds a Master's degree in business administration and has extensive experience of operational topics such as engineering.

Wolfgang Bernhart (Stuttgart) is Partner at Roland Berger Strategy Consultants in Germany. He is responsible for all activities related to new technologies (such as electrification of the powertrain), engineering and R&D within the Automotive Competence Center. He has more than 18 years of experience working in consulting and in the automotive industry, focusing on globalization, R&D, new business model design and performance improvement. He studied production engineering at the University of Karlsruhe and has a PhD from the Institute for Machine Tools and Operations Technology.

Jun Shen (Shanghai) is Partner at Roland Berger Strategy Consultants in China and leads the Automotive Competence Center at Roland Berger Greater China. He has in-depth knowledge and expertise in the functional areas of corporate strategy, mergers & acquisitions, operational benchmarking, organizational restructuring and sales & marketing management. He holds an MBA from China Europe International Business School (CEIBS) and a Bachelor's degree in engineering from Shanghai Jiao Tong University.

Authors

Stephan Keese (São Paulo) is Principal at Roland Berger Strategy Consultants in Brazil and is responsible for Roland Berger's automotive practice in Latin America. Over his 10 years of consulting experience based out of Munich, Germany and São Paulo, Brazil he has worked with leading automotive players in nearly all major automotive regions. He has experience in the areas of corporate strategy, business performance improvement, distribution channels and corporate finance. He holds a degree in Industrial Engineering from the University of Karlsruhe and an MBA from Georgetown University.

Alberto Fernandez (Stuttgart) is Project Manager at Roland Berger Strategy Consultants in Germany. He focuses on commercial vehicles within the Automotive Competence Center. During eight years of consulting and industry experience worldwide he has developed a deep knowledge of commercial vehicle OEMs and their suppliers. Since 2006 he has focused in particular on alternative powertrains for commercial vehicles, conducting several projects in this area. He holds a Master's degree in electrical engineering from the universities of Oviedo (Spain) and Munich (Germany).

Frank Pietras (Munich) is Senior Consultant at Roland Berger Strategy Consultants in Germany. Within the Automotive Competence Center he focuses particularly on the commercial vehicle, agricultural and construction vehicle cluster. His three years of automotive consulting allowed him to deepen his automotive industry experience by participating in various OEM and OES projects. He holds a diploma in international management from Magdeburg University.

Co-authors

Ralf Kalmbach (Munich) is a member of the executive board at Roland Berger Strategy Consultants and leader of the global Automotive Industry Practice. In his 20 years of consulting experience in the global automotive and manufacturing industries, he has focused strongly on corporate strategies and business designs. He holds a Master's degree in mechanical engineering and business administration from the University of Karlsruhe (TH).

Jochen Gleisberg (Stuttgart) is Partner at Roland Berger Strategy Consultants in Germany. He focuses on the globalization of operations such as R&D/ engineering, procurement and product planning, as well as on the globalization of organizational models and processes. His eleven years of consulting experience to date have given him a strong focus on the truck industry (OEMs and suppliers) and the engineered products industry. Gleisberg is also responsible for the Roland Berger "China Desk Germany". He holds a Master's degree in Business Administration.

Axel Schmidt (Stuttgart) is Partner at Roland Berger Strategy Consultants in Germany. He is the leading partner of the CC Operations Strategy practice worldwide and the responsible partner for the Stuttgart office. He has more than 20 years of consulting experience. His project focus is on engineering, purchasing, supply chain and production as well as on strategy, organization and performance improvement programs.

Boris Firsov (Moscow) is Partner at Roland Berger Strategy Consultants in Russia. He is co-leader of the Automotive Competence Center at Roland Berger Russia and CIS. He has in-depth experience in various areas of the automotive industry, including strategy, R&D, manufacturing, sales and after-sales. He has worked extensively in Russia for global OEMs, Russian automakers, suppliers and dealers. He holds a diploma in engineering from the Baltic Technical University (Russia) and an MBA from the Kellogg Graduate School of Management (Illinois, USA).

Co-authors

Satoshi Nagashima (Tokyo) is Partner at Roland Berger Strategy Consultants in Japan. He leads the Automotive Competence Center in Tokyo. In his 13 years of consulting experience at Roland Berger he has specialized in developing strategies for sales, marketing, distribution channels, product planning and engineering. He holds a PhD in material science.

Jürgen Reers (Detroit) is Managing Partner for the North American Region at Roland Berger Strategy Consultants. He leads the Automotive Practice in North America and has over 15 years of consulting experience working with top manufacturers, suppliers and retailers worldwide in the automotive, commercial vehicle and construction/off-highway equipment sectors. He has a strong background on issues of corporate strategy, marketing and sales, R&D and supplier management. He holds a Master's degree in business administration.

Max Blanchet (Paris) is Partner at Roland Berger Strategy Consultants in France, in charge of automotive activities. He focuses on engineering, manufacturing and distribution topics. In 14 years of consulting experience he has been involved in key issues in the automotive sector, including strategy, operational improvement (R&D, supply chain, purchasing, manufacturing) and corporate performance (organization and SG&A optimization).

Amsterdam
Bahrain
Barcelona
Beijing
Berlin
Brussels
Bucharest
Budapest
Casablanca
Chicago
Detroit
Düsseldorf
Frankfurt
Hamburg
Hong Kong
Istanbul
Kyiv
Lisbon
London
Madrid
Milan
Moscow
Munich
New York
Paris
Prague
Riga
Rome
São Paulo
Shanghai
Stuttgart
Tokyo
Vienna
Warsaw
Zagreb
Zurich

www.rolandberger.com