STUDY

Integrated Fuels and Vehicles Roadmap to 2030+

Presentation handout

April 27, 2016

1. Background and Motivation

In October 2014, the 2030 Climate and Energy Policy Framework set a binding target of 40% for the reduction of greenhouse gas (GHG) emissions in 2030 compared to 2005, along with non-binding targets for renewable energy and energy efficiency improvements. The overall 40% GHG reduction target includes a 30% reduction for non-ETS sectors that includes transport.

The absence of a long-term regulatory framework – standards for new vehicle GHG emissions, carbon intensity of fuels and use of renewable fuels are defined only until 2020/2021 – is creating uncertainty for investment in low carbon vehicle and fuel technologies. This study proposes a view on technical achievability, infrastructure requirements, customer acceptance and costs to society of GHG abatement measures to derive supporting policies.

For this purpose, Roland Berger defined an Integrated Roadmap for EU Road Transport Decarbonization to 2030 and beyond. The study was commissioned to identify possible reductions in GHG emissions by considering the key elements of technical achievability, infrastructure needs, customer acceptance and which policies, currently being pursued, would lead to greater integration between the automotive and fuel sectors in order to meet the challenging decarbonization goals set out to 2030 and beyond. This study aims to provide an integrated roadmap taking into account the feasibility of all fuel and vehicle technologies along with infrastructure needs and the recommended policy framework beyond 2020. A key consideration was to identify a roadmap with the lowest, achievable GHG abatement costs to society.

Existing data and views from a very broad range of accepted studies and stakeholders were used in the performance of this study.

2. Modelling approach and assumptions for reference case

The study quantifies, in a realistic reference case, potential GHG emission reductions under the current regulatory framework with predicted market improvements. The abatement effect of enabling vehicle and fuel technologies is assessed with a comprehensive vehicle fleet and fuel model for EU-28, covering GHG emissions from passenger cars, light commercial vehicle and other commercial vehicles as well as indirect emissions from fuel and electricity production.

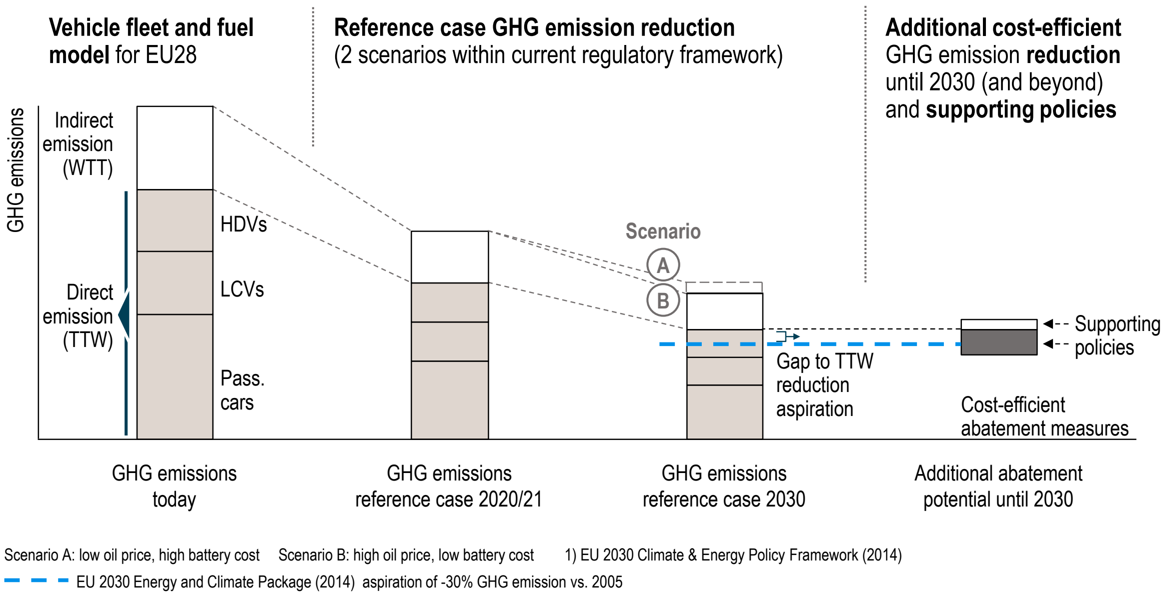
For the model, the likely powertrain mix for different vehicle groups until 2030 has been derived. These powertrain mix forecasts are based on projected fuel and vehicle costs for conventional internal combustion engines (ICE), mild and full hybrids, and alternative powertrains such as plug-in hybrids (PHEV), battery electric vehicles (BEV), natural gas vehicles (CNG) and fuel cell electric vehicles (FCV). The reference case predicts, within two different scenarios for oil price development and battery technology progress, an expected market development for each technology under the current regulatory framework. For the reference case, the model assumed extension of the existing legislation to 2030, without the addition of any other policies.

After comparing transport sector emissions under the current regulatory framework with the 2030 GHG emissions reduction targets[1], technologies were identified to achieve additional GHG

[1] The Climate & Energy Policy Framework from 2014 aims to achieve a 30% reduction in GHG emissions below the 2005 level until 2030 in non-ETS sectors. The 2011 White Paper for Transport defines transport emissions to be calculated on a tank-to-wheel basis.

abatement at the lowest cost to society. In order for these technologies to contribute to the abatement of road transport sector GHG emissions, the recommended policies need to address the current obstacles these technologies face.

Figure 1: Approach for development of integrated roadmap



Source: Roland Berger

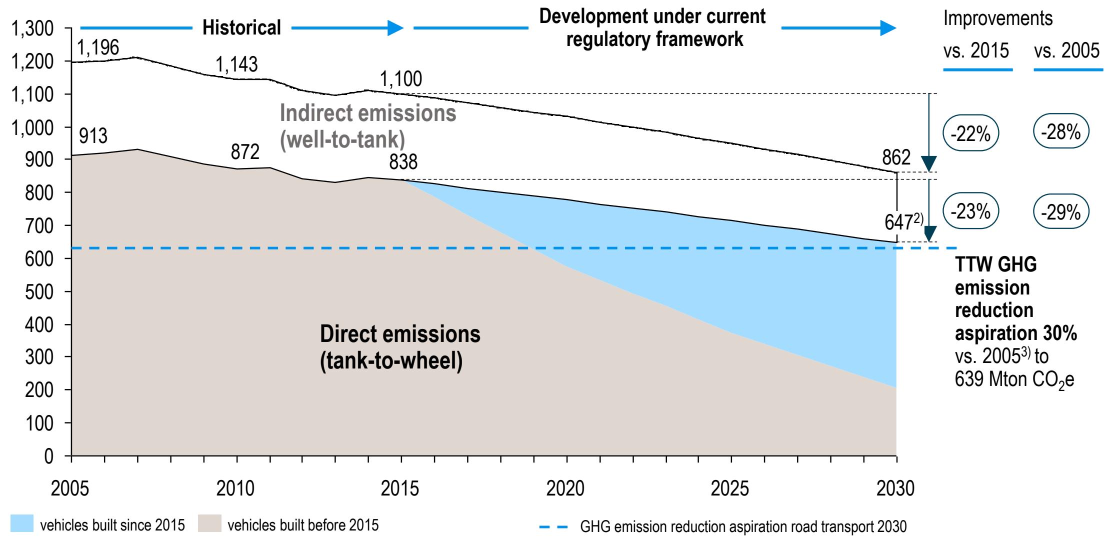
3. GHG emissions reduction towards 2030 in reference case

Based on assumptions developed in conjunction with a wide range of stakeholder input and reference studies regarding vehicle fleet development and the current regulatory framework, the study has shown that the road transport sector will

> Significantly reduce tank-to-wheel GHG emissions by 2030 to 647 Mton CO_2e/a. This represents a reduction of 29% compared to 2005 levels and is close to the reference level chosen for this study of -30% vs 2005 based on tank-to-wheel emissions. The reference level was set based on the 2030 non ETS target and the EC White Paper 2011 methodology of measuring transport emissions (tank-to- wheel).

The study also shows that the continuation of the current policies for vehicle emissions and renewable fuels obligations will deliver well-to-wheel GHG emission reduction from 1,100 Mton CO_2e/a in 2015 to 862 Mton CO_2e/a.in 2030.

Figure 2: EU-28 road transport sector GHG emissions[1] in reference case (Scenario A: low oil price) [Mton CO_2e/a]

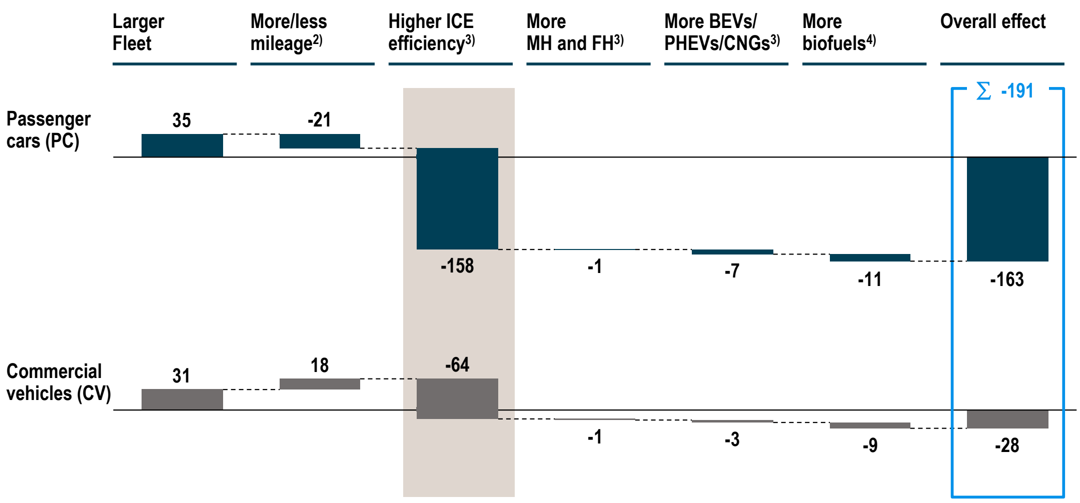


1) Fleet emissions of passenger cars and commercial vehicles, excluding two-wheelers, biofuels considered TTW carbon-neutral
2) Scenario A: low oil price, high battery cost 3) Based on EU 2030 Climate & Energy Framework (2014) reduction aspiration for non-ETS sectors

Source: UNFCCC/EEA; EU 2030 Climate & Energy Framework; Roland Berger

The study shows that moving forward from 2015 optimized ICEs (gasoline and diesel) and biofuels usage are the major contributors to the sector's GHG emission reduction with significant improvements and the subsequent penetration of effective technologies into the fleet. Despite the expected reduction in cost of alternative technologies, the share of alternative new car sales will remain relatively small and their influence on overall emissions currently remains marginal. Even until 2030 many alternative powertrain technologies such as PHEV, BEV and FCV lack relative cost competitiveness but are important corner stones in vehicle manufacturers' CO_2 emission compliance strategies.

Figure 3: Road transport direct GHG emissions by influencing factor 2015 vs. 2030 [Mton CO_2e/a]



ICE – Internal combustion engine MH – Mild hybrid FH – Full hybrid BEV – Battery electric vehicle PHEV – Plug-in Hybrid electric vehicle CNG – Compressed natural gas
1) Biofuels accounted as TTW zero CO_2 emission 2) Average annual mileage per vehicle 3) Higher penetration in fleet compared to 2015 **(fleet renewal effect)**
4) Increasing E10 share in gasoline fuel until 2030, increasing FAME and HVO shares in Diesel fuels

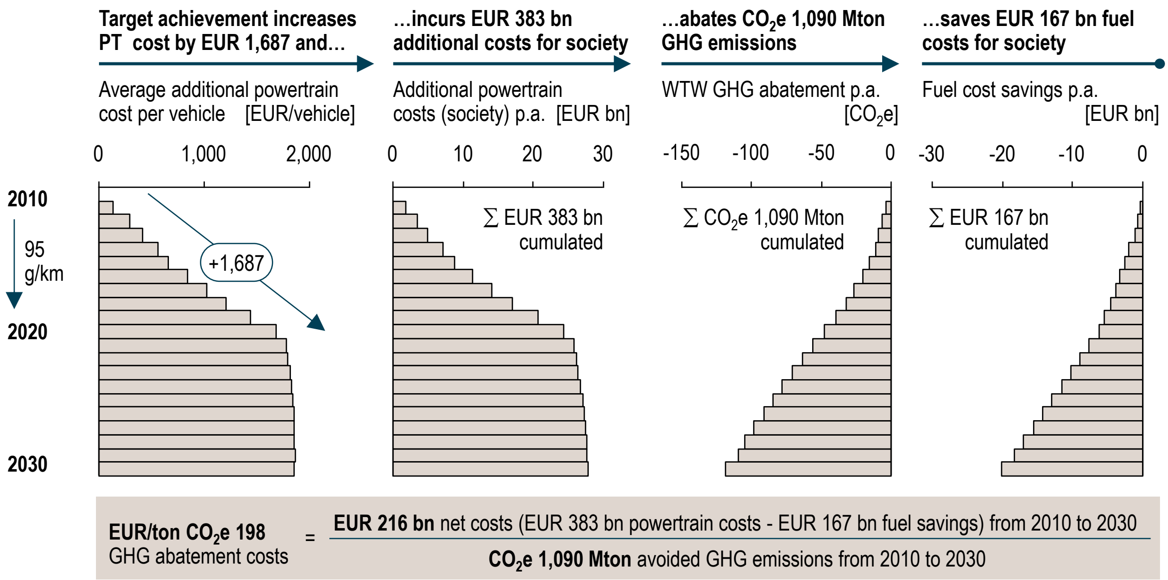
Source: Roland Berger

Bringing optimized ICEs as well as alternative fuels and powertrain technologies to market represents a major challenge for the oil and auto industries and will account for EUR 380-390 bn of cumulated incremental powertrain costs from 2015 until 2030 (average incremental powertrain cost 2020 vs 2010: approx. EUR 1,700 per vehicle)

The incremental powertrain costs identified have the following overall effects:

> Cumulated GHG abatement of approx. 1,100 Mton CO_2e/a,
> Fuel cost savings between EUR 170 and 220 bn and
> Average societal abatement cost of approx. ~ 150- 200 EUR/ton CO_2e after deduction of fuel savings depending on the oil price scenario

Figure 4: Effect of current policy framework for GHG emission abatement – Low oil price scenario



Source: Roland Berger

4. Additional potential for GHG abatement: 2030 and beyond

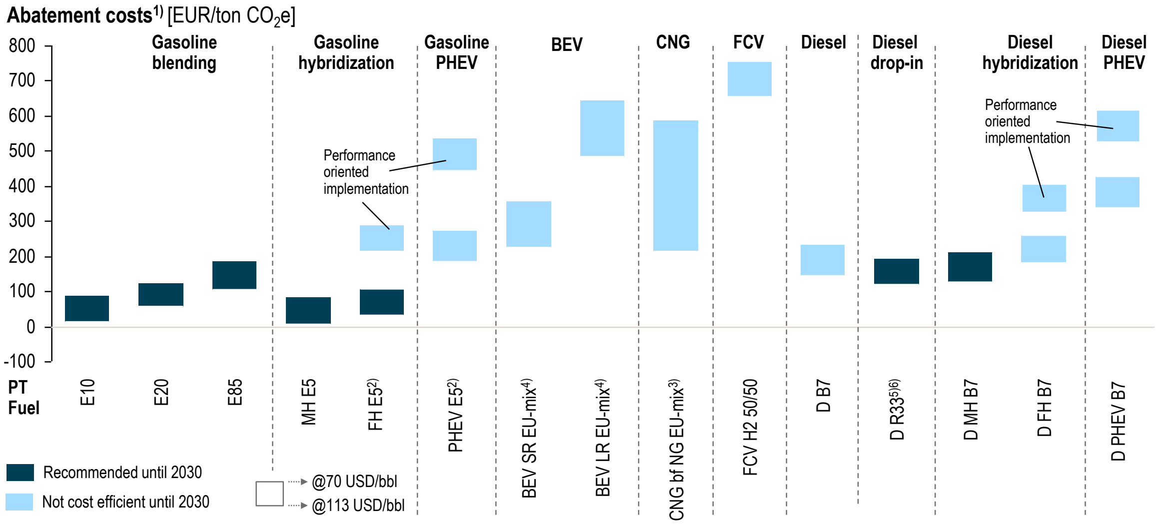
For passenger cars to deliver further reduction of GHG emissions until 2030 by, it is cost-efficient for society to promote

1. Uptake of higher advanced ethanol blends, such as E10, E20 for gasoline,
2. Uptake of drop-in advanced and waste based biofuels for diesel such as R33[2] and co-processing of renewable feedstock in refinery units and
3. Uptake ultra-high efficient hybridized powertrains, such as mild hybrids and full hybrids

as these technologies are not yet fully capitalizing full GHG emission reduction potential in terms of deployment under the current regulatory framework.

[2] Diesel fuel with 7% FAME and 26% HVO

Figure 5: WTW GHG abatement costs pathways, C-segment PCs 2030 [EUR/ton CO_2e]



1) Compared to optimized Gasoline powertrain 2030 using E5, all technologies with 250,000 km lifetime mileage 2) 30% e-driving, higher e-driving share reduces abatement costs
3) Large range between scenarios driven by decoupling effect of natural gas price 4) Risk of higher abatement costs due to need of second battery over lifetime,
SR – short range with 35 kWh battery capacity, LR – long range with 65 kWh battery capacity, both using 2030 EU mix electricity, 5) Diesel fuel with 7% FAME and 26% HVO
6) Abatement cost in existing vehicle: -67 EUR/ton CO_2 (high oil price), 7 EUR/ton CO_2 (low oil price)

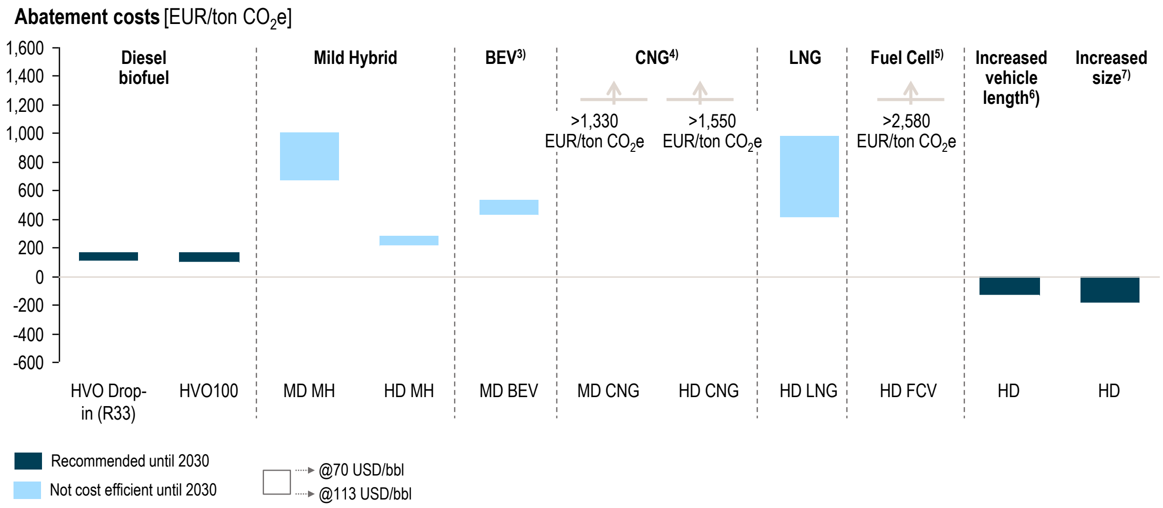
Source: Roland Berger

In commercial vehicle segments Light Commercial Vehicle (LCV), Medium Duty Trucks (MDT) and Heavy Duty Trucks (HDT), additional cost-efficient GHG abatement is possible through

- Higher uptake of drop-in advanced biofuels for diesel
- New HD truck concepts with increased gross vehicle weight and higher maximal length for improved aerodynamics with even negative abatement cost.

Alternative powertrain (e.g. BEV, PHEV) measures in these segments are very costly to 2030 due to high adaptation and integration cost.

Figure 6: WTW GHG abatement costs pathways of medium- and heavy duty vehicle 2030 [EUR/ton CO_2e]



1) Medium duty 2) Heavy duty 3) Exclusion of HD BEV due to incompatibility of BEV range with long haul requirements 4) High CO_2 abatement costs for CNG and LNG within MD/HD/City Bus s result from low quantities of vehicles (missing economies of scale) and CO_2 abatement potential compared to Diesel is small (<5% savings/km) 5) High system cost and low lifetime mileage in medium duty trucks causes very high abatement cost , therefore incompatibility 6) Increased efficiency due to aerodynamic measures to reduce drag 7) Length and gross vehicle weight increase, increased transport efficiency by 10%

Source: Roland Berger

The identified cost-efficient abatement technologies in passenger cars and commercial vehicles allow approximately 34 Mton CO_2e/a of additional WTW GHG emission reductions down to 828 Mton CO_2e/a in 2030.

As a longer-term requirement (**beyond 2030**) for the EU road transport sector, the only combinations of fuel and vehicle pathway technologies that are technically able to realize "ultra-low carbon mobility" are

> Highly-efficient conventional powertrains fuelled with advanced and waste based biofuels

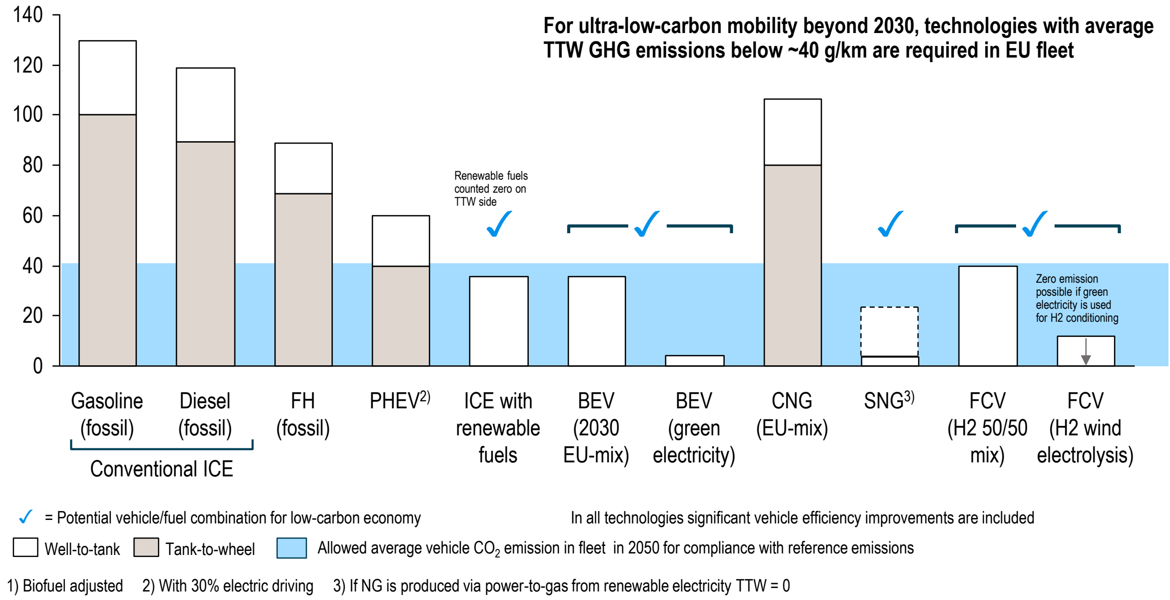
> PHEVs fuelled with advanced biofuels and renewable or carbon free electricity

> BEVs fuelled with renewable or carbon free electricity

> FCVs fuelled with renewable hydrogen

These vehicle and fuel technology combinations would allow average vehicle CO_2 emissions of the fleet to come down to below 40 gCO_2/km, which could lead to overall fleet GHG emission reductions below the expected level for 2050 (60% reduction compared to 1990 as defined in in the EC White Paper 2011).

Figure 7: WTW GHG efficiencies by technology[1], average C-segment vehicle 2030 [g/km]



Source: Roland Berger

5. Policy recommendation

The current regulatory framework does not fully address all the barriers preventing a higher penetration of biofuels and hybrids for passenger cars to achieve the 2030 GHG reduction target. It is recommended that additional policies are introduced to provide greater investor certainty and improve consumer demand for these lower cost abatement options.

In many commercial vehicles the implementation of efficiency technology in powertrains is driven by Total Cost of Ownership (TCO) – Only in LCVs, the implementation of fuel-saving measures segment is supported by the current regulations. But, at vehicle level, an adaption of the regulatory framework on current vehicle length and weight limitation is necessary.

Figure 8: Key obstacles cost-efficient abatement options

Fuel with high advanced biofuel share	MHs and FHs for passenger vehicle	Highly efficient truck concepts
Remaining uncertainty regarding **sustainable demand** (price and volume)	**High purchasing cost**[1)] for customers and lack of **TCO benefits**	
Cost competitiveness vs. conventional fuels (in all scenarios)		
Technology hurdles for advanced generation		
Uncertain **vehicle compatibility/lack of fuel standards**		Regulatory limitation of **vehicle length and weight**
Lack of customer **technology awareness and knowledge**	Lack of customer **technology awareness and knowledge**	

1) incl. other registration cost (e.g. purchasing taxes)

Source: Roland Berger

Until 2030, in addition to continuation of current policies for fuels and vehicles new demand- and supply-side policy measures are needed at EU and member state level to address the obstacles preventing further market penetration of low abatement cost options and to enable these technologies (e.g. biofuels and hybrids). This integrated approach aims to:

> Create a long-term sustainable market (demand-side) to
  – Encourage consumers to buy carbon-saving vehicle technologies
  – Incentivize fuel customers to choose low carbon fuels by providing a strong price signal either via a tax exemption of biofuel content in market fuels in combination with an additional CO_2 based taxation component or via a fuel taxation bonus depending on the biofuel content in combination with an additional CO_2 based taxation component
  – Improve customers awareness about technological benefits of efficient powertrains and cost-attractiveness

> Create planning security for investments by fuel suppliers and OEMs (supply-side) to
  – Enable the development of advanced biofuel production by providing a strong and sustained price signal for the product through tax exemptions or bonus/malus systems as for incentivise consumer demand
  – Support the use of the Innovation Fund for investments in innovations in low carbon technologies. The Innovation Fund should be used to fund capex and opex for initial advanced biofuel plants (fuel supplier/biofuel suppliers)
  – Increase the production of cost-efficient vehicles as well as highly efficient conventional technologies and fuel compatibility of vehicles (OEMs)

Roland Berger

Figure 9: Overview of key obstacles of pathway technologies: high biofuels share fuels, MHs/FHs and new truck concepts

	Fuel with high biofuel share	MHs/FHs power-trains for PC	Highly efficient trucks
	Existing supportive policies at fuel supply side (e.g. transport RED targets, provision within DAFI/AFID) and vehicle side **kept unaltered**		
Additional financial instruments	> Introduce **additional fuel taxation components** enabling a price advantage for fuels with high advanced biofuel share, e.g. – Biofuel bonus/malus + CO_2 component – Biofuel tax exemption + CO_2 component > Support the use the Innovation Fund for invest-ments in innovations in low carbon technologies	> **Change existing vehicle taxation towards a CO_2 based taxation**, e.g. – CO_2 based vehicle registration tax – CO_2 based annual vehicle tax – CO_2 based vehicle usage tax	
Additional regulation/ liabilities	> Set **tailpipe emission to zero** for the renewable part of the fuel that the vehicle is compatible with, above 2020 levels – define reference fuels accordingly		> Adjustments in truck **length and weight regulation**
Additional other policies	> Introduce **CO_2 labeling for fuels** > Offer/support "**customer education**" for biofuels > Make fuel **taxation transparent** to customer (e.g. at gas station)	> Introduce **cost/TCO labeling** for vehicles	

Taxation as powerful financial instrument is in responsibility of member states, additional regulation and liabilities can be introduced on EU level

Source: Roland Berger

Policy recommendations beyond 2030

In line with the long-term EU vision of a low-carbon society, it is further necessary to develop instruments that drive progress towards cost-effective ultra-low-carbon mobility. It is recommended that policy makers consider placing fuels in a market based mechanism (MBM) as complementary policy to vehicle emission standards, fuels and infrastructure policies. Initially, the MBM should be designed to recycle the revenues from the sale of allowances for fuels to provide the funding needed to bring new low carbon fuels and vehicles to market. Once low carbon fuels and vehicles can be deployed affordably en masse, the MBM can be the primary GHG reduction policy and other policies (vehicle efficiency, fuels etc.) can be removed.

Figure 10: Market-based mechanisms as future policies for long-term GHG emission reduction

Long-term policy requirements

- The required additional GHG emission abatement beyond 2030 **require additional supporting policies**[1)]
- Market-based mechanisms (**MBM**) are an option **as complementary policy** to vehicle CO_2 standards, fuels and infrastructure policies
- Initially, MBM should be used to **generate revenues** to fund new low carbon vehicle and fuel technology to reach market competitiveness
- Once low carbon vehicle and fuel technologies are competitive, MBM can become the **primary GHG reduction policy** replacing other vehicle efficiency, fuels related policies

Design principles for a market-based mechanism

The following design principles ensure cost-effective and transparent GHG emissions reduction

- **Fuels suppliers** should be the **obligated party**
- **All** emissions **allowances** need to be **purchased** and can be traded
- Only **direct CO_2** emissions (TTW) should be included in the **cap**
- **Biofuels** (meeting sustainability criteria) should be accounted for as **zero TTW** CO_2 emissions

1) EC White Paper (from 2011) suggests a 60% GHG emission reduction by 2050 with respect to 1990

Source: European Commission, ZEW, ICCT, IW Köln, Roland Berger

To achieve the target of a cost-effective and transparent reduction in GHG emissions, the following design principles of a market based mechanism are recommended:

- Fuel suppliers should be the obligated party
- All emissions allowances need to be purchased via government auction and can be traded
- Only CO_2 emissions from the combustion of fuels should be included in the cap and should be calculated based on average TTW emissions (CO_2/unit volume for gasoline and diesel)
- Biofuels should be accounted for as zero CO_2 TTW emissions for the part that the vehicle is compatible with above 2020 levels and only those that meet agreed sustainability criteria should be allowed for compliance
- Funds from auctioning allowances for fuels should be used to provide time limited support for both the additional policies for advanced biofuels, hybrids or ultralow carbon technologies as well as R&D into these technologies

6. Summary Integrated Fuels and Vehicles Roadmap to 2030+

> **On the basis of a detailed EU28 road fleet model** developed by Roland Berger it appears that by extending **existing policy** measures to 2030, the road transport sector can reduce TTW emissions by **~29% to 2030** (vs. 2005) reaching almost the 2030 aspiration – Compared to today, 2030 WTW GHG emissions should reduce by 238 Mton, thereof 191 Mton reduction are direct emissions

> Abating ~1,100 Mton CO_2 emissions cumulative in passenger cars from 2010 to 2030 reflects **cost to society** of an estimated **~200 EUR/ton CO_2e** this includes significant cost incurred by vehicle manufactures and fuel suppliers

> Identified cost-efficient abatement **pathways** (fuels with higher biofuel shares, hybridization in passenger cars and highly efficient truck concepts) would allow **additional** GHG abatement of approximately **34 Mton CO_2e until 2030**. This reflects an annual emission saving forecast in 2030, which will further reduce post-2030 with the deployment of these technologies in the fleet

> Additional policies are needed to address obstacles **to the deployment of low-carbon** pathway technologies such as

- supporting development of advanced **biofuels via price signal** to the biofuel/fuel industry
- an **adjusted fuel and vehicle taxation** (e.g. excise duty exemption or taxation bonus/malus on advanced bio-components in fuels in combination with a CO_2 based taxation component)
- **adjusted** regulations regarding **biofuel's TTW emissions** (set tailpipe emission to zero for the renewable part of the fuel that the vehicle is compatible with above 2020 levels and to define reference fuels accordingly) to accelerate the penetration of vehicles that are compatible with higher concentrations of biofuels
- adjusted regulations of **truck length and weight limits** to improve aerodynamic efficiency and transport efficiency by increased payload levels
- making low-carbon technology benefits more **transparent to the customer**

> In the long term, **market-based mechanisms** (MBM) are an option as complementary policy to vehicle CO_2 standards, which would provide **Member States with funds** to support new ultra-low-carbon vehicle and fuel technologies – In the **long term** MBM can become **primary** GHG reduction policy

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