Strategic roadmap

WITHIN THE INITIATIVE STRATEGIC VEHICLE RESEARCH AND INNOVATION (FFI)

Energy and Environment

03/11/2015

FFI Strategic Vehicle Research and Innovation

VINNOVA · Swedish Energy Agency · TRAFIKVERKET SWEDISH TRANSPORT ADMINISTRATION · FKG · SCANIA · VOLVO

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1 Aim and Objectives

This document comprehensively describes the FFI programme's[1] link to the area
Energy and environment. The document is a strategic roadmap containing a description of the challenges, research and development needs, as well as the expected results.

The document is intended, through regular updates, to get all parties to jointly agree on the need for research and development activities that contribute to increased energy efficiency and reduced emissions of greenhouse gases, at the same time as other emissions such as noise, particulates and nitrogen oxides are also reduced. In addition, the roadmaps will be an instrument for monitoring and evaluating, and for increasing understanding of the FFI programme by illustrating the correlation between the funded activities and the expected effects within the programme's area. This document primarily attempts to clarify what needs to be done to achieve the overall objectives of the programme within the area until and including 2030, and thereby contribute to:

- At least 55 per cent energy efficiency (kWh/vehicle-kilometres) by 2030 through competitive passenger cars (base year 2008).
- Fifty per cent energy efficiency (kWh/tonne kilometres) from commercial vehicles (trucks, buses and construction machinery) by 2030. These 50 per cents are divided roughly equally between vehicle development and increased transport efficiency (base year 2008).
- Develop vehicle technical conditions to result in at least 85 per cent of fuels in the road transport sector being renewable by 2030.
- Emissions, such as noise, particles and nitric oxides, must be reduced to meet the maximum levels for these pollutants, particularly in sensitive areas and larger cities (mega cities).
- The Swedish automotive companies have taken this step and have become world leaders in the development of energy efficient and environmentally friendly vehicles.

Secondly, an attempt will be made to look further into the future, in some cases as far forward as 2050. For natural reasons, this description will be less detailed and uncertainty greater the farther forward we look. It is important to see the individual development paths from a systems perspective and use as complete a life cycle analysis (LCA) as possible. The following are the 3 main objectives laid down for the transport sector in the EU White Paper[2] 2011.

- A reduction in emissions of greenhouse gases in accordance with the long-term obligation to limit climate change to 2°C and the overall EU target to reduce emissions by 80 per cent by 2050 compared with 1990. Transport-related CO_2 emissions should be reduced by about 60 per cent by 2050 compared with 1990.
- A drastic reduction of the quota for oil-related transport-related emissions by 2050, which is required in the EU's 2020 strategy for transports, which calls for transports with lower carbon dioxide emissions.
- Limited increase of traffic congestion.

[1] *http://www.vinnova.se/sv/ffi/*
[2] *http://register.consilium.europa.eu/doc/srv?L=SV&t=PDF&gc=true&sc=false&f=ST%208333%202011%20ADD%201*

2 Background

2.1 Energy and climate

Energy supply to the transport sector is unique compared with other sectors of society in the sense that a single source of energy covers almost the entire demand. Across the world today, about 95 per cent of fuels come from crude oil. The remaining 5 per cent is mainly made up of 2 per cent natural gas and 3 per cent comes from various renewable fuels, especially ethanol and bio-diesel (FAME).

In 2012, domestic transport accounted for 33 per cent of Swedish greenhouse gas emissions (cars [3]19 per cent, trucks and buses 12 per cent and other domestic transport 2 per cent).
Emissions of greenhouse gases from road transports were greatest in the years 2005 to 2007, when they were 12-13 per cent greater than 1990. Since then, emissions have fallen, mainly from passenger cars, and emissions in 2012 were only 2 per cent higher than in 1990. New passenger car fuel consumption has fallen by 25 per cent since 2007, and by 40 per cent since 1990, where fuel consumption has decreased from 5.8 l/100km (144 g CO_2/km) in 2011 to 5.5 l/100 miles (138 g CO_2/km) in 2012. This reduction is a result of more energy-efficient vehicles, as well as an increase in the proportion of diesel vehicles. Fuel consumption was also reduced for new light lorries and in the corresponding years consumption decreased from 7.2 l/100km (189 g CO_2/km) in 2011 to 6.9 l/100km (180 g CO_2/km) in 2012[4].

In 2012, energy consumption in the Swedish transport sector was 90 TWh[5]. In recent years petrol use in the Swedish transport sector has followed a declining trend and at the same time, diesel use has increased. The share of energy from renewable sources in the transport sector amounted in 2012 to 8.0-12.6 per cent[6], depending on the calculation method. Ethanol, various bio-diesel options and bio-gas are the renewable fuels currently used primarily for vehicle operation. Ethanol is partly used as a low-level mixture in petrol and as a component of such fuels as E85 and ED95. Ninety-six per cent of the petrol sold on the Swedish market in 2011 contained ethanol. FAME, fatty acid methyl ester, is a bio-diesel option that is produced mainly from rapeseed in Sweden and is used both in its pure form and as in additive to fossil diesel fuel. Around 82 per cent of the diesel sold on the Swedish market in 2011 contained FAME. In 2011, the bio-diesel option HVO, hydrogenated vegetable oils, was introduced to the Swedish market. Automotive gas is composed of pure bio-gas, pure natural gas or a mixture of the two and the mix varies across the country. The proportion of bio-gas in automotive gas in recent years has been around 65 per cent.

According to the IEA International Energy Agency, overall greenhouse gas emissions, calculated on the basis of the 1990 emissions, need to be cut in half by 2050. Because developing countries account for a smaller proportion of emissions, and the same requirements as the developed countries probably cannot be applied to them, they are only required to reduce their emissions more than the average reduction. Based on this, the Swedish government has decided the following:

- In 2030, Sweden should have a vehicle fleet that is independent of fossil fuels. To achieve this, energy efficiency needs to be increased and renewable energy needs to be promoted.
- In 2050, Sweden should have an energy system without net emissions of greenhouse gases, which means fossil fuel-free vehicle traffic[7].

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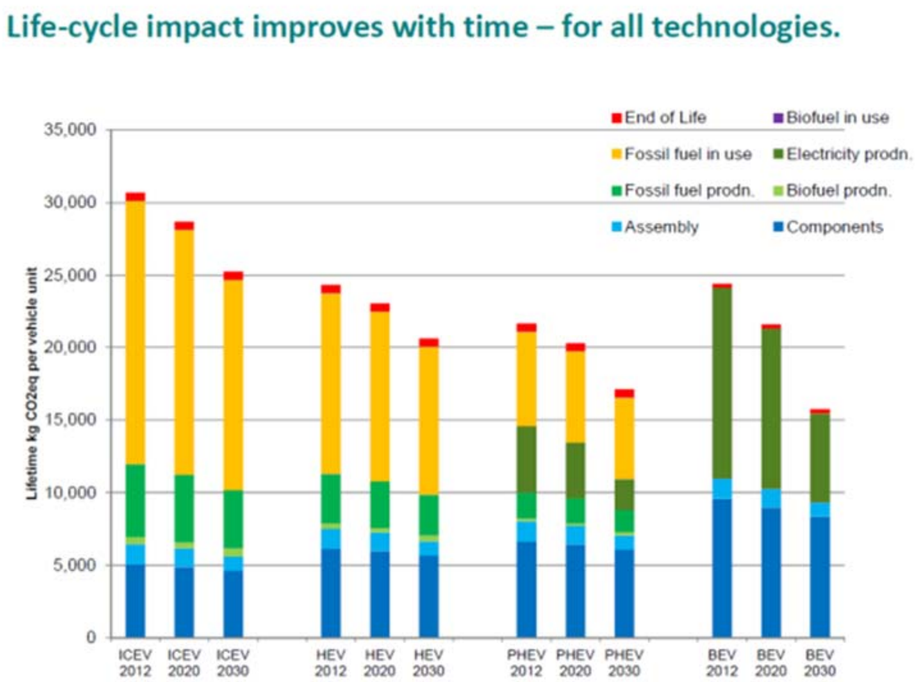
[3] *Swedish Environmental Protection Agency. National emissions of greenhouse gases 1990-2012. http://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Vaxthusgaser--nationella-utslapp/*
[4] *Swedish Transport Administration, Reduction of greenhouse gas emissions from road traffic, memo, September 2013 http://www.trafikverket.se/PageFiles/116546/pm_vagtrafikens_utslapp_130902_ny.pdf*
[5] *The Swedish Energy Agency, Energiläget 2013 [the energy situation 2013].*
[6] *Sweden's second progress report on the development of renewable energy pursuant to Article 22 of Directive 2009/28/EC. http://ec.europa.eu/energy/renewables/reports/2013_en.htm*
[7] *http://www.regeringen.se/content/1/c6/17/99/14/b35baf9f.pdf*

Meeting this challenge requires efforts both in terms of technology development and means of control. The report concerning fossil fuel-free vehicle traffic defined a fossil independent vehicle fleet by 2030 as reducing emissions from road traffic by approximately 80 per cent.

The Swedish Transport Administration defines the area with the greatest potential for limiting the transport sector's climate impact by 2030 as passenger cars. This would be done through such measures as energy efficiency, increased share of renewable energy, and urban planning and transition from the car to public transport. As far as energy efficiency is concerned, the Transport Administration believes that energy use per kilometre for light vehicles can be more than halved by 2030 and for other vehicles and traffic types, the potential is around 20-40 per cent. There is also considerable potential for energy efficiency in infrastructure maintenance. The potential for energy efficiency gains for light and heavy vehicles and the increased share of renewable energy (including electric) should be about the same size[8].



To reduce fossil fuels in the transport sector, the FFI programme intends to support technological development, with the main focus on improving the vehicle but the related areas of eco-driving, logistics, inter-modality and production efficiency will also be included to some extent.

Table1: Summary of CO_2 emissions during the phases of passenger cars' life cycle, for technology levels of conventional vehicle (ICEV), hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and pure electric vehicles(BEV). The table shows the total carbon dioxide emissions from different types of vehicle over its entire lifetime. The table also shows that emissions are partly composed of emissions from the actual operation of the vehicle and of emissions caused by manufacture of the vehicle. The manufacture proportion becomes an increasing part of the total CO_2 load since operation on the vehicle becomes more efficient (described above by the electrification rate increasing). That is why it is all the more important to include emissions from manufacture in an overall environmental assessment of a vehicle.[9]

One of the possibilities for energy efficiency in the transport sector is electrification. Electricity has a very effective “tank-to-wheel” efficiency at the same time as local emissions of nitrogen oxides completely

[8] *Swedish Transport Administration, Trafikslagsövergripande planeringsunderlag för Begränsad klimatpåverkan [traffic types' overall planning basis for limited climate impact], 2010:095.*
[9] *PE International for Low Carbon Vehicle Partnership, Lifecycle CO2 Assessment of Low Carbon Cars 2020-2030, 2013*

disappear and particles and noise are reduced. For an electric car, the estimated efficiency is approximately three times higher than that of a conventional power train in a passenger car. Even if the electricity is produced with relatively low energy efficiency in e.g. coal-fired power stations (which in themselves have very high carbon dioxide emissions), the total energy efficiency is higher in electric vehicles than for conventional vehicles equipped with an internal combustion engine, see the table below. It should, however, be noted that the calculations vary in different studies and that there are uncertainties in the future potential for improvements both for vehicles equipped with internal combustion engines and for electric vehicles. Among other things, the extra energy used for heating in an electric vehicle is often ignored.

Table 2: JEC[10] Energy use in passenger cars with different powertrains in 2020

PISI (Petrol)	150 MJ/100 km
DISI (Diesel)	142 MJ/100 km
DISI full hybrid (Petrol)	93 MJ/100 km
DICI (Diesel)	119 MJ/100 km
DICI full hybrid (Diesel)	88 MJ/100 km
BEV (Electric)	38 MJ/100 km
DISI PHEV* (Electric, Diesel)	67 MJ diesel/100 km 10 MJ/100 km (Electric)
FCEV (Hydrogen)	54 MJ/100 km

**For PHEV, the electric range is dimensioned to be at least 20 km*

Long distance heavy transport vehicles with batteries as the primary energy supply are not realistic with current battery technology, because the battery size required would completely eliminate payload capacity for these vehicles. So-called electric roads and continuous power supply opens up the possibility for electric operation for long-distance heavy transport vehicles.

A widespread introduction of electric vehicles will result in an increased demand for electricity. In the event of electrification of today's Swedish passenger car fleet and road networks, the increase in electricity consumption is expected to amount to approximately 12 TWh per year, which corresponds to about 9 per cent of the Swedish electricity consumption[11]. The increase in electricity consumption will require an increase in production capacity or savings in other sectors. The change can also require upgrades of the electrical distribution system, such as implementation of smart networks where supply and demand are controlled in a more active way than today. It is probably only justifiable to electrify the backbone road network used by heavy goods vehicles, which means that these vehicles must be equipped with hybrid powertrain systems and a complementary energy-efficient internal combustion engine. This means infrastructure for renewable fuel or fuels with low greenhouse impact will probably be required, partly because of this vehicle type.

The effects of the change from an internal combustion engine vehicle to an electric vehicle has not been fully examined yet and results may vary considerably, depending on the methods for the production of the electricity itself and the overall efficiency of the system. It can be argued that the greenhouse gas emissions for electrical transport will be regulated, as its use will be within the greenhouse gas trading system. But the savings in this system is not ensured as long as the system is specific for the EU since leakage effects may occur. At the same time, an increase in electricity consumption could lead to revisions to the trading system so that its requirements are not set too high because of increased use. Therefore, the reasoning that any increase in electricity in the EU leads to zero emissions is a simplified and perhaps incorrect method for assessing emissions from increased electricity generation.

[10] *JEC updates well-to-wheels study on Automation fuels and powertrains; electro-mobility, natural gas and biofuels. Green Car Congress. 27 March. 2014. link*

[11] *Per Kågeson, Klimateffekten av elektrifierad vägtrafik [the climate impact of electrified road traffic], 2010.*

When assessing changes in electricity consumption, there should be a causal connection between the choice/intervention and changes in emissions from electricity consumption. Per definition, it is the marginal electricity that changes when there is a change in energy use, while there is a small/insignificant corresponding change in average electricity consumption. Attempts to establish the marginal electricity in the literature point toward fossil fuels in the marginal production up to 2030, while in the long term to 2050 there is an increase in the amount of renewable electricity in the system.

For future use of electricity for transports, the dynamic modelling of marginal electricity is recommended as the preferred method of assessment. This margin improves with time and in a scenario where society manages to balance the level of greenhouse gases at 450 ppm in the atmosphere, electric vehicles look promising. Marginal electricity thus has high emissions in a short term perspective, but this should not prevent the introduction of electric vehicles, as they deliver a significant reduction in greenhouse gases in a future scenario where renewable electricity and the introduction of technologies for carbon capture and storage (CCS) reduce carbon dioxide emissions from electricity production. An idea of emissions from future electricity production can also be obtained by considering the consequences of the agreed upon international climate target known as the 2 degree target. Research shows that to achieve the two-degree target, all energy sectors throughout the world must achieve almost zero emissions around 2070-2090. Research also shows that the electricity sector can reduce carbon dioxide emissions at a lower cost compared to the transport sector, which indicates that electricity production must change earlier or at the same rate as the number of electric vehicles in the market is increasing, if the climate target is to be achieved.

In the case of future transport volumes, it may be worth noting that trends point in different directions. Many future scenarios show an increase in the amount of road transport, especially heavy traffic, as there is currently a strong link between economic growth and the amount of freight transport. There are also studies showing that global urbanisation will continue, which will affect user patterns for passenger cars. A continued trend towards centralisation, such as with shopping centres, points toward an increasing need for car ownership. At the same time, future car use patterns are affected by a lower proportion of young people getting a driving license. More than one in five persons age 25-44 did not have a licence in 2012, compared with one in ten at the end of the 1980s.[12]

No unambiguous picture of future energy carriers for passenger cars has yet to emerged. Towards 2020, the existing fuel types on the market are expected to increase. This includes everything from electric to vehicles running on commercial fuel to natural gas and, probably after 2020, increasingly tailored synthetically manufactured fuels. A conservative voice in this context belongs to British Petroleum. In its “BP Energy Outlook 2030, EU insights”, it forecasts that 91 per cent of the total transport volume in the transport sector will still use oil, while gas and biofuels will cover 4 per cent. However, opinions differ widely in different studies, where the predicted approach often coincides with the world view of the funder of the analysis.[13]

From an environmental point of view, CO_2 emissions for a given energy content are most interesting. Good fuels, manufactured in environmentally friendly ways, can provide a significant contribution here. These may even be compatible with the existing vehicle fleet. Electricity as an energy carrier provides great potential for improvement, which stands or falls with access to “green electricity” and charging infrastructure. The production of fuels are, however, not discussed within FFI and are only listed as boundary conditions here.

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[12] *Swedish Transport Administration, Reduction of greenhouse gas emissions from road traffic, memo, September 2013 http://www.trafikverket.se/PageFiles/116546/pm_vagtrafikens_utslapp_130902_ny.pdf*
[13] *Hansson and Grahn, “The future prospects for renewable fuels in Sweden", IVL B2083, 2013.*

2.2 Noise

About 100 million people in Europe regard themselves as being disturbed or very disturbed by road traffic noise in their residential environment. This leads to considerable losses, which can be translated into economic consequences for society and individuals. The World Health Organisation (WHO) has calculated that welfare losses correspond to about 1 million lost healthy life years (Healthy Life Years indicator (HLY))[ref.] for the affected persons every year in Europe[1]. Losses can also be calculated in lower economic value for noise-exposed properties, production losses from direct impact, increased fatigue and sick leave, etc. In contrast to many other causes of major health issues in society, such as traffic accidents and air pollution, noise-related problems are expected to increase in the future if the trends continue as before. Increased urbanisation and traffic result in greater recurring problems than society's response can handle at the current pace it is introducing noise protection measures, such as fences and quieter road surfaces. Measures to reduce noise and prevent its spread from vehicles and tyres, as well as preventing its spread using road noise fencing, quieter road surfaces, traffic planning, infrastructure and building planning is therefore necessary. Further research (e.g. in the form of FFI projects) to establish relevant target levels for the road system and its stakeholders, as a function of time, should be initiated.

2.3 Harmful emissions

Over the past decades, emissions of harmful substances from vehicles have decreased as new technologies for reducing emissions have become available and stricter exhaust requirements have been introduced. Still, air quality problems remain, especially in our large towns and cities when it comes to particulate matter and nitrogen oxides. Globally, we see major air quality issues in large cities and a number of EU member countries have difficulty not exceeding air pollution limits, while the EU is debating whether to impose stricter limits. Within the EU, regulations and methods are being developed for both light and heavy vehicles to ensure low emissions in other driving situations than the type-approval test cycle[14].

The introduction of new fuels and mixtures requires developing an understanding of their characteristics and effects on health. This applies to both regulated emissions (CO, HC, NOx and particulates) and to currently unregulated substances such as PAHS, aldehydes and more. (These may be unregulated in the EU but this is not the case in all markets)

Harmful emissions are not only generated by the engine's combustion process but also from e.g. evaporation and wear processes in the vehicle and in the interaction between the vehicle and the road surface. It is important to better understand sources beyond the combustion process, such as evaporation and wear particles and their effects.

3 Status and development potential for the Energy and environment area

3.1 Approach

It is possible to describe FFI activities in many ways and the perceived results are influenced by the approach taken. In the development of its roadmap, the sub-programme Energy and environment has chosen the following two aspects as its starting point:

- Description of milestones and possible concepts
- The Energy and environment programme's sub-programme areas

[14] *Within the UNECE, development of the World Harmonised Light Vehicle Testing Procedure (WLTP) is in progress. Also under development is the European procedure for "real driving emission" (RDE). The Euro VI World harmonised Heavy Duty certification procedure (WHDC) applies for heavy duty vehicles.*

The first aspect tries to identify a number of low CO_2 vehicle concepts that are fully possible to introduce on the market by 2030. The description stays at a generic level. The reasons for this is to simplify manufacturing (the same concept for passenger cars as for, e.g. heavy goods vehicles) and to respect the needs of companies' for confidentiality when it comes to technology and product plans. These concepts are linked to a “milestone", that is to say a time when the necessary research, testing and demonstration must be completed so that an industrialisation phase, outside the FFI, can begin.

The second aspect is based on the Energy and environmental programme's sub-programme areas:
- Energy-efficient propulsion (power train)
- Concept for propulsion using renewable fuels, electric traction and so on.
- Vehicle optimisation (including methods for testing and validation) for minimised environmental, noise and health impacts
- Energy efficient vehicles (not power train)
- Business and economic models for the transport sector’s energy systems including vehicles, traction and energy carriers.

The above areas partially overlap and a particular project may very well cover several programme areas. Regardless of the classifications that are chosen in a presentation like this, such overlaps and demarcation problems need to be managed.

In some cases goals may conflict between technology areas. One such case is the optimisation of diesel engine emissions of nitrogen oxides and its energy efficiency. If the engine is optimised completely on energy efficiency, the emissions of nitrogen oxides increase and if the engine is optimized completely for low nitrogen oxide emissions, energy efficiency falls.

In the presentation below there is both a focus on technology and an approach that views road safety from a systems perspective. In addition, such aspects as the FFI programme can directly affect are primarily described. Other factors (such as the need for new standards or new legislation) are also identified but without their form and content being described further.

3.2 Principle outline

A sustainable and systematic approach will be required if the desired results in the current milestones are to be achieved. At a general level, these efforts can be regarded as a permanent interaction between research and preparatory development, testing and implementation.

The FFI permits a wide range in the types of results produced. For some of innovative or fundamental results, it may take decades before it is technically and economically feasible to take advantage of relevant knowledge. And because they often involve risky projects, some will never successfully be implemented in products and services. On the other hand, results produced using a scientific approach can make an impression on product and service development at an early stage. Combinations of both of these forms are common, e.g. a long-term project that incorporates lots of research elements where new knowledge is continually siphoned into companies' pre-development or product development departments or are introduced into research and education at universities and university colleges. This allows parts of the work needed to reach a specific milestone useful long before the intended market introduction of the finished concept.

The FFI should also contribute to the creation of excellence within universities and university colleges, which in turn increases the attraction for education in the specific area, thereby increasing general levels of competence. It also increases the ability of businesses to bring in the various needed competencies through employment. A special focus should be given to strengthening priority research communities, such as the already established centres.

The figure below illustrates the above reasoning graphically.

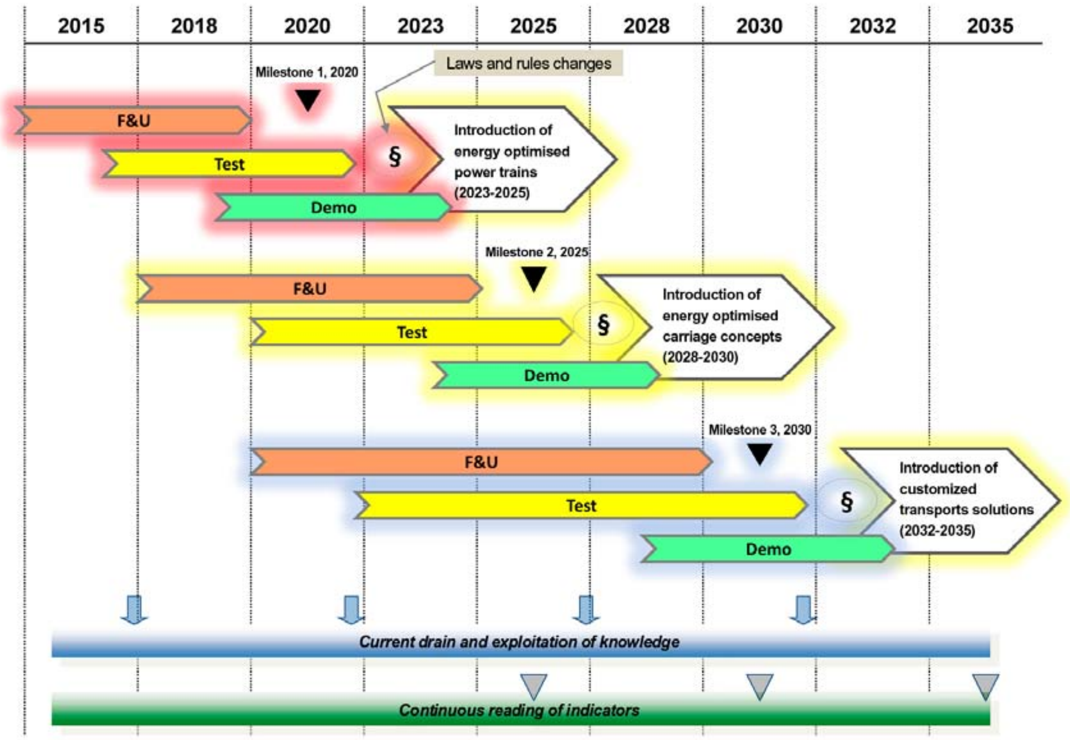


Figure 1: *Principle outline of research, testing and demonstration activities within FFI Energy and environment*

When it comes to the results of the programme, FFI is part of the EU Commission initiative entitled "Innovation Union" and shares its ambition to "get more innovation from our research to catch up with our main competitors". It is not just that more knowledge in general must be gained but also that research results need to be translated much faster into practical applications.

The board of FFI, alongside the programme committees, must fund pioneering initiatives directly. These would primarily be projects which, if they succeed, will lead to major leaps of technology or other crucial changes with relevance for the area. This type of project may also be run by the programme committee. The programme committee also supports projects that are best described as refining (the work of developing further an already used concept or approach) or enabling (activities of a knowledge-building or general nature).

4 Research and development areas within FFI Energy and environment

The programme Energy and environment is oriented towards vehicle-related research, innovation and development in the following areas:

- Energy-efficient propulsion (power train)
- Concept for propulsion using renewable fuels, electric traction and so on.
- Vehicle optimisation (including methods for testing and validation) for minimised environmental, noise and health impacts

- Energy efficient vehicles (not power train)
- Business and economic models for the transport sector energy systems, including vehicles, traction and energy carriers.

4.1 Energy-efficient propulsion

This research area focuses mainly on energy use in the propulsion system. The main areas are the development of combustion systems including charging, continued work to minimise losses in the power train, including the use of exhaust heat, and not least the development of new advanced and consumption- and cost-optimised power train concepts. Among the latter, various hybrid concepts have particularly good potential to reduce fuel consumption. Research is needed, both at concept and at subsystem levels. For electric hybrids, the most important subsystems are energy storage, the electrical equipment, including the power electronics and control system. An important aspect of a broader market introduction of hybrids is that the cost of these subsystems be reduced. Examples of areas of focus:

- Power train concepts (electric, electric hybrid and plug-in hybrids, including cost, energy and power parameters)
- Systems and components (e.g. power electronics, electrical equipment and energy storage) including the control of these at the system level
- The tank or charging system for alternative fuels or electrical system, including fire and (electrical) safety
- Combustion concepts, such as DI and HCCI
- Gas exchange, charging systems and recovery of exhaust energy
- Transmission technology, including tribology

4.2 Concept for propulsion using renewable fuels

The introduction of renewable and environmentally friendly fuels on the market is a key issue for reducing emissions from fossil CO_2. The characteristics of renewable fuels differs in important aspects from current fuels. These differences impact both the combustion and emission formation processes and phenomena such as wear and corrosion. The new fuels' characteristics must be identified and their connection to physical and chemical processes that affect emission formation needs to be explored. Examples of areas of focus:

- Engine development for renewable fuels (e.g. such biofuels as alcohols, methane, bio-diesel and DME).
- Energy converters suitable for renewable fuels (e.g. free piston engines or fuel cells).
- Optimisation and conversion of existing power trains to use renewable fuels.

4.3 Vehicle optimisation for minimising environmental, noise and health impacts (excluding CO_2)

Combustion of the fuels results in residual products with potentially harmful effects on human health and the environment (depending on the exposure levels, exposure times and so on). The catalysts and other components of the exhaust after treatment system can effectively reduce emissions, but new fuels bring their own set of challenges. New fuels and stricter emission requirements will lead to the exhaust after treatment components representing an every larger part of the product cost and occupying greater physical space in the vehicles. The reduction in the use of precious metals in catalytic converters and similar are important for conserving resources and controlling costs. In addition, tyre wear and noise emissions from cars cause health problems from the substances released from the plastics, rubber, varnishes and so on used to meet customer requirements for different vehicle characteristics. In this area there research projects can be coordinated to examine the health effects of emissions. The initiator could be the Environment Protection Agency or any other party in the programme. Examples of areas of research

- Emission formation
  - o Particles, nitrous oxides, toxic substances, carcinogenic substances and so on
  - o Re-connected combustion for emission reduction at low ambient temperatures (cold start)
- Exhaust after treatment

    - at low exhaust temperatures
    - choice of catalytic materials, including recovery
    - reduced use of precious metals in the after-treatment systems
- Sound pollution and vibrations (both for the user and the environment outside the vehicle, as a result of the vehicle's operation)
- Health effects
- The health and safety aspects of the use of alternative fuels and electric operation (such as fire and Electro Magnetic Compatibility (EMC))

4.4 Energy efficient vehicles (not power train)

Despite the efficiency improvements and development of drive systems, measures are also needed for the vehicle itself, its other systems and such aspects as electrified roads to improve the energy efficiency of the transport sector. Aerodynamics and light weight are important areas, the latter being discussed in the Sustainable Production sub-programme. In addition, there are also a large amount of energy consumers in the vehicle that directly or indirectly need energy. Research efforts will be necessary to improve energy systems for these needs in an energy-efficient and cost-effective manner. Examples of areas of research

New vehicle concepts (e.g. city vehicles, “80-tonne transport vehicles”) including requirements to social acceptance, lifetime and so on

- Energy systems in the vehicle e.g. air condition
- Support for energy efficient use of vehicles such as Human Machine Interface (HMI)
- External energy supplements
- Design optimisation
- Rolling resistance
- Aerodynamics
- APU system for electricity generation
- Trailer design (for heavy goods vehicles)
- Energy efficient machinery, including hydraulic systems
- Electrified roads (mainly in the FIFFI strategic field)

4.5 Business and economic models for the transport sector’s energy systems including vehicles, power trains and energy carriers

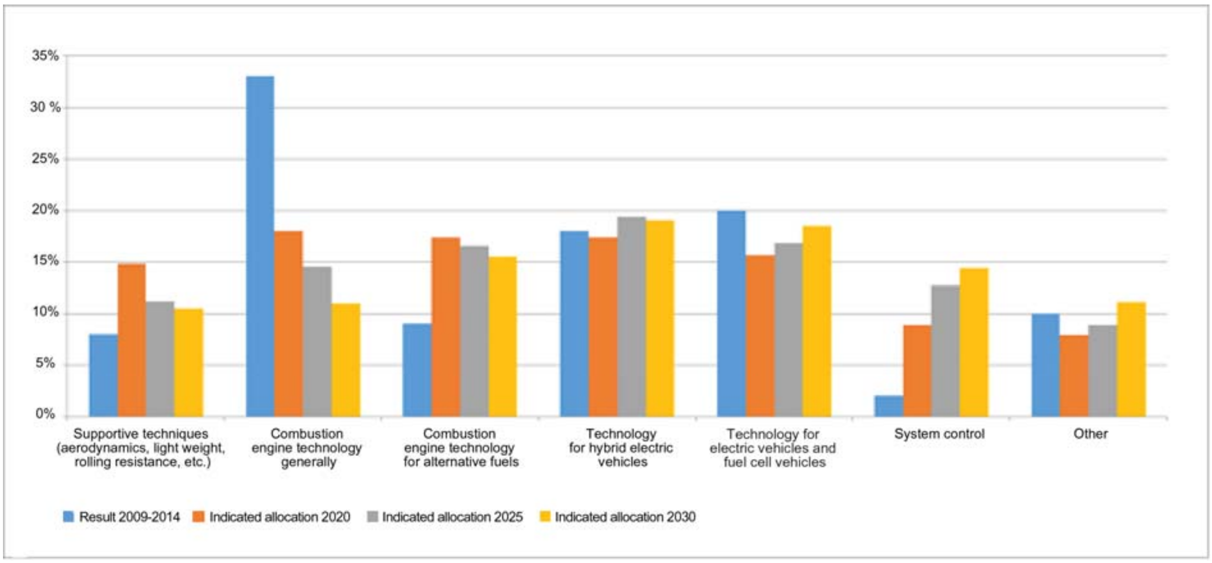
The success of the above four research areas will give the Swedish automotive industry a solid starting point. There is good potential for developing competitive and, in some cases, world-leading technologies and for introducing these in future product programmes. These activities must, however, also be associated with commercial considerations: Are there sufficient customers who are willing to pay for the new features or the improved efficiency? Experience shows that new technologies adoption by users and vehicles owners is slow, mainly because of the extra cost initially incurred at their introduction.

- Economic Energy and environmental models that analyse the barriers to the introduction of new technologies in the transport sector
- The development of control systems based on the above models, for example technology procurement, financial instruments and administrative rules.
- Analysis of the social cost and the effect of different technologies and system choices, based on such things as market potential, for example the production of alternative fuels including infrastructure for distribution, life cycle cost of the vehicle's power train.

5 Future milestones

FFI will contribute to reduced environmental impact of road transports. Since FFI in Swedish stands for "vehicle strategic research, development and innovation", it is natural that FFI's efforts are essentially about vehicle-relevant activities in early phases of development. The results will be used by the participating companies in their development of new or improved products and services. In projects in which academia is involved, the new findings will be utilised in advanced research and new material for instruction. To illustrate what the development supported by the FFI can contribute to, three different future milestones have been defined based on when the anticipated market introduction of new technologies will occur. The milestones are divided into three categories of vehicles because market distribution and market introduction are expected to be very different between these vehicle types. As there is no data on the current distribution per vehicle type for the period 2009-2013, average values for the entire programme were chosen. The charts, therefore, mainly provide an indication of the trends in the distribution rather than any exact amount. Nor is it likely that the research funds will be distributed evenly between these categories of vehicles. For example, city buses account for only one per cent of the total CO_2 emissions from the area. To try to gain an approximate overall picture of how future research funds within the FFI Energy and environment may be distributed, the three categories of vehicles have been weighted below. The weighting factors were 30 per cent for passenger cars, 10 per cent for city buses and 60 per cent for long-distance transport vehicles.

2015 Total indicated allocation of research funding in per cent within the FFI Energy and environment per technology area and time period



Global warming is a worldwide problem that requires global solutions. Swedish vehicle manufacturers are large global players and more than 90 per cent of their production is exported. This means that Swedish research in the field should not only relate to Swedish targets and scenarios but also targets in the rest of the world. To this end, the background information for the following milestones has been taken both from Swedish reports, such as "Fossil freedom on the road", and from similar foreign scenarios.

5.1 Milestones for passenger cars

5.1.1 Background information

Reference from SOU 2013:84 Fossilfrihet på väg [Fossil freedom on the road] and IVL B2083, 2013 Utsikt för förnybara drivmedel i Sverige [Future prospects for renewable fuels in Sweden]

Share of traffic, % of total number of vehicle kilometres driven on renewable solid, liquid and gaseous fuels

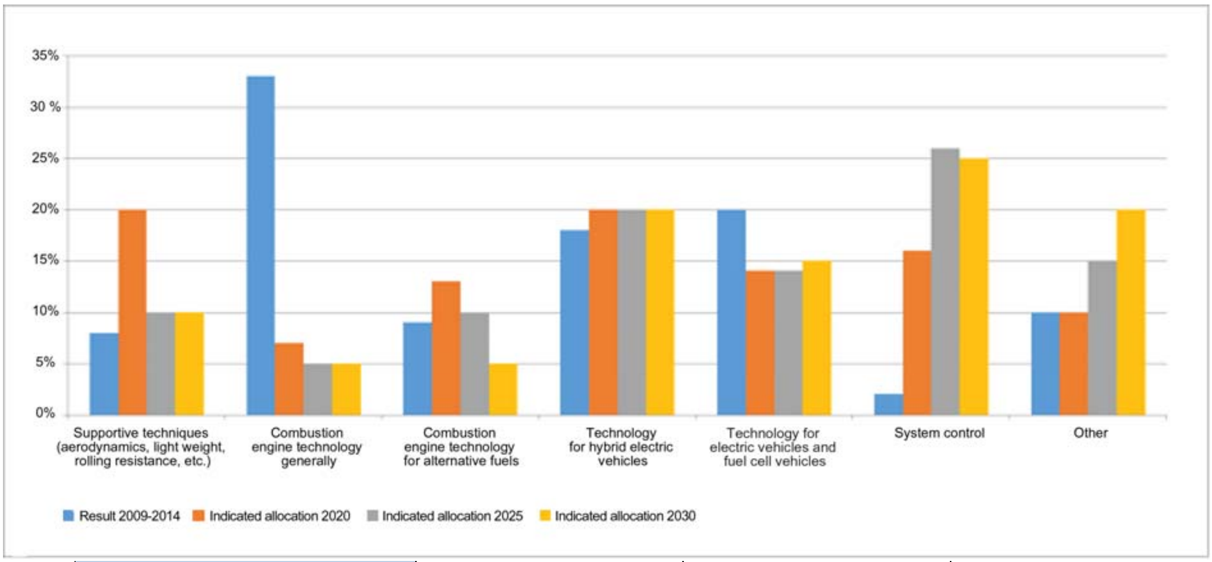
	2020	2025	2030
Sweden*	20%	35%	50%
Other countries	3-5%	5-8%	5-10%

Share of traffic, % of total number of vehicle kilometres driven on electric

	2020	2025	2030
Sweden*	1-5%	10%	20%
Other countries	1-5%	3-5%	5-20%

5.1.2 Milestones for FFI Energy and environment, Passenger cars

	Milestone 2020 On the market 2023-2025	**Milestone 2025** On the market 2028-2030	**Milestone 2030** On the market 2033-2035
Milestone CO_2 Emissions, gram CO_2/vehicle kilometre energy efficiency+ alt. fuel	70	50	"0"
Milestone Energy Efficiency (% lower kWh/person kilometre compared with base year 2008)	45%	50%	>55%
Milestone Noise (certified level at the vehicle) (Swedish Transport Administration's estimate)	66 dB	63 dB	"58 dB"
Milestone Other emissions	The Euro VI levels that are increasingly met in real traffic throughout the life of the vehicle and for all certified fuels		
Trends in the area and emphasis on research	Large-scale solutions for plug-in hybrid vehicles	Vehicles designed for fully autonomous driving	Fully autonomous driving is standard on new cars
	Vehicle concepts with lower drive resistance due to smaller size	Intermittent operation of combustion engine, NVH measures complete vehicle	Ownership forms for passenger cars may have changed completely. Virtually only pool cars remaining
	Friction measures on and part-electrification of the power train, WHR	Some form of electricity-charging/ use is standard	The vehicle size is selected according to the task to be performed
	Use adaptation to fully synthetic fuels Advanced charging and combustion	The demand for "pure" battery vehicles depends on how the charging infrastructure has been developed	Access to clean electricity and purely synthetic fuels is good



		and the availability of "clean" electricity	

2015 Indicated allocation of research funding in % within the FFI Energy and environment for passenger cars per technology area and period

5.1.3 The introduction of new technologies and the connection between the vehicle and the environment

Wider introduction of new technologies is the greatly dependent on the extent to which they can demonstrate their strengths during customer testing when making a purchase decision. A transition to the WLTP driving cycle and away from the current NEDC will influence the development of technology on the market. As the cycle as a whole has not been fully developed yet, the impact is not fully known. However, it has already become clear that this partial move to WLTP in itself will not interrupt the trend for energy consumption increasingly deviating from nominal values. There are, however, good reasons for this[15] and, regardless, the development of the technology is driven towards improvements. But users need to be aware that there is a transfer function between certified consumption and practical consumption that is not linear. In the longer term, the picture is more uncertain. Incentives, tax rules and how costs develop, especially in electrification, will strongly affect the numerical balance between different technological solutions, since technological transitions, even assuming an increasing cost of energy, are not cost neutral for end customers. The value of a gram of better fuel efficiency in a private vehicle is around SEK 300[16] while the typical net cost of technological measures to gain a gram is at least twice as high. With current cost trends, controls will be needed in the long term if the customer is to perceive the investment as profitable.

Improving the efficiency of the transport system with passenger cars will take place mainly through:

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[15]*Certification cycles have always been intended as quality tools for monitoring that products comply with their specifications and, to lesser extent, were created for predicting consumption that is relevant for the customer. This is not entirely known and often leads to misunderstandings.*

[16]*Assumption: 3 year loan, 15,000 km/year, fuel costs SEK 18/l. The FFF2030 study assumes that customers estimate the financial benefit throughout the service life of the vehicle and thereby comes to a more advantageous interpretation. It remains to be seen which type of estimate customer will make. In its material about rulemaking 2017-2025, the EPA assumed that most US customers could not imagine car loans longer than 2 years.*

- More efficient vehicles,
- More efficient power trains and
- More efficient use of the vehicles

More efficient vehicles means more customised vehicles for the job of transports and HMI interfaces that intuitively convey the most efficient use to the driver. Factors for this include aerodynamics, effective help systems, reduced friction and rolling resistance, lightweight concepts and smart HMI solutions. For the power trains, liquid fuels are expected to be the main option during the period but some form of electrification will become increasingly common. It will be necessary to adapt the power trains to the fuels available on the markets, including biofuels. The exchange of both energy carriers and information with their surroundings and with the traffic systems' infrastructure will greatly contribute to reducing energy consumption per kilometre. Efficiency improvements on the power train are accomplished primarily by highly efficient combustion with optimal control, brake energy recovery, minimising use of low-efficiency operating points for the internal combustion engine and systematic work to reduce friction. More and more effective support systems, from the gear shift indicator to semi-autonomous systems, such as convoy driving (vehicles that drive very close to each other and where all of the vehicles are in some way controlled by the first vehicle driver) will likely evolve.

In the short term, power train development in particular will result in better energy efficiency through improved energy conversion, with maintained trailer concept because these are locked in existing industrial infrastructure.[17] A relatively new trend to extract shale gas in higher proportions has the potential to create a more stable and larger market for gas-fuelled cars. The potential for CO_2 reduction is, however, minimal. Consumers and functions for other needs than pure propulsion will will have to address significant efficiency requirements. Electrification has not seen a breakthrough on the volume market yet, and costs need to adjust before these solutions will have wider customer acceptance and market penetration. **In the medium term**, energy-optimised trailer concepts will have a greater impact on reducing total energy consumption of net benefit (propulsion, air conditioning and so on). The cost of technologies that reduce fuel consumption will encourage trend reversal away form increasingly larger cars in the industry and will lead to necessary work to transfer engineering knowledge to a smaller scale and create new knowledge for the introduction of new materials. Much of this material development will take place in hybrid solutions, i.e. solutions where different engineering materials are mixed with each other. Fully synthetic fuels, with tailored properties, begin to appear and will drive some product customisation, perhaps even alternative circuit processes in combustion engines. In the even longer term, new tailored transport solutions and changes in user patterns can lead to further improvement of the energy efficiency in passenger cars. Incentives, tax rules and how costs develop, especially in electrical vehicles with only battery operation, will strongly affect the numerical balance between different technological solutions, since technological transitions, even assuming an increasing cost of energy, are not cost neutral for end customers.

[17] *For example, development of the Audi A2 has cost approximately SEK 3.5 billion. Since only half the number of planned cars were sold, Audi is assumed to have lost around SEK 70,000 per vehicle, with a total loss estimated to be over SEK one billion. Losses from the Smart FourTwo were almost three times higher. With this kind of huge risk, the established automotive industry tends to be conservative. Only new players (Tesla) dare to take drastic steps. Source: Euro Autos: The 10 most loss making cars of modern times (or what happens when it all goes wrong), Bernstein Research.*

5.2 Milestones for city buses

5.2.1 Background information

Reference from SOU 2013:84 Fossilfrihet på väg [Fossil freedom on the road] and IVL B2083, 2013 Utsikt för förnybara drivmedel i Sverige [Future prospects for renewable fuels in Sweden]

Share of traffic, % of total number of vehicle kilometres driven on renewable solid, liquid and gaseous fuels

	2020	2025	2030
Sweden*	35%	20%	10-15%
Other countries	5-10%	5-15%	5-20%

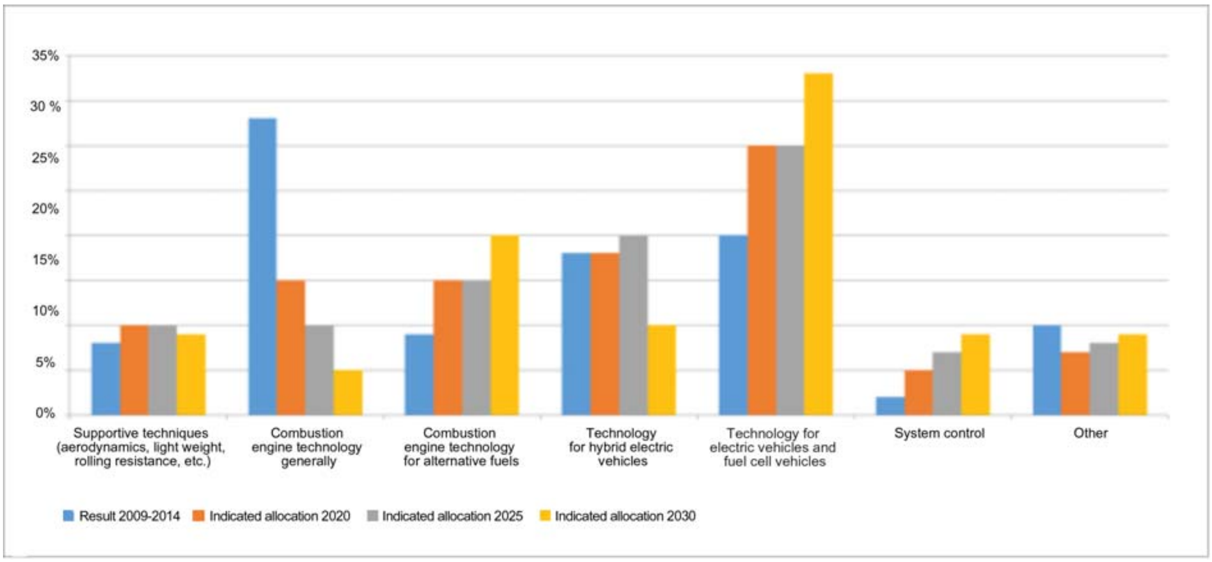
Share of traffic, % of total number of vehicle kilometres driven on electric

	2020	2025	2030
Sweden*	15-20%	40-50%	80-85%
Other countries	5-15%	20-30%	30-50%

5.2.2 Milestones for FFI Energy and environment, City buses

	Milestone 2020 On the market 2023-2025	**Milestone 2025** On the market 2028-2030	**Milestone 2030** On the market 2033-2035
Milestone CO_2 emissions (% lower CO_2 emissions/person kilometre compared with base year 2008) (energy efficiency + alt. fuel)	65%	80%	"100%"
Milestone Energy efficiency (% lower kWh/person kilometre compared with base year 2008)	40%	55%	60%
Milestone Noise (certified level at the vehicle) (Swedish Transport Administration's estimate)	72 dB	68 dB	65 dB
Milestone **Other emissions**	The Euro VI levels that are increasingly met in real traffic throughout the life of the vehicle and for all certified fuels		
Emphasis on research	Pure electric buses and plug-in hybrids	Pure electric buses	Electric roads
	More efficient heating and air conditioning	Clearer LCA perspective in the design and manufacture of the vehicles. Vehicles adapted to their tasks.	

5.2.3 2015 Indicated allocation of research funding in % within the FFI Energy and environment for city buses per technology area and period



Demands increase from society that public transport should be used more to reduce both local and global emissions. For city buses, this means that greater attention is given to capacity usage and counting grams CO_2/passenger kilometre will be decisive for passenger transport. This means that taking a bus in the city needs to be much more attractive. For buses to be an attractive choice, they need to be the cornerstone of local transport and offer

- flexibility
- energy efficiency
- minimised local noise and emissions
- availability
- comfort

and is environmentally friendly with low local and global emission of e.g. nitrogen oxides, noise and CO_2.

Continually increasing urbanisation leads to the growth of our cities. “Mega-cities” form in the world with completely different requirements for passenger transport. Local emissions are increasingly important and more and more cities are divided into different environmental zones. This means that the statutory emission requirements are not enough, and local rules will also apply. Moving from combustion of fossil oil to environmentally friendly biofuels and being able to electrify will be decisive for how attractive city buses for passenger transport in cities. Standards and specifications need to be developed to address future needs if buses with their associated benefits and with better environmental performance to increase bus use.

Another important issue for the future of city buses is to keep their weight down, even with the addition of new equipment. Knowing about and understanding how to use lighter materials and how different types of materials can be added together can be crucial for the ability of buses to compete with other modes of transport from a financial perspective.

5.3 Milestones for heavy road vehicles for haulage

5.3.1 Background information

Reference from SOU 2013:84 Fossilfrihet på väg [Fossil freedom on the road] and IVL B2083, 2013 Utsikt för förnybara drivmedel i Sverige [future prospects for renewable fuels in Sweden]

Share of traffic, % of total number of vehicle kilometres driven on renewable solid, liquid and gaseous fuels

	2020	2025	2030
Sweden*	25%	50%	90%
Other countries	3-5%	5-8%	5-10%

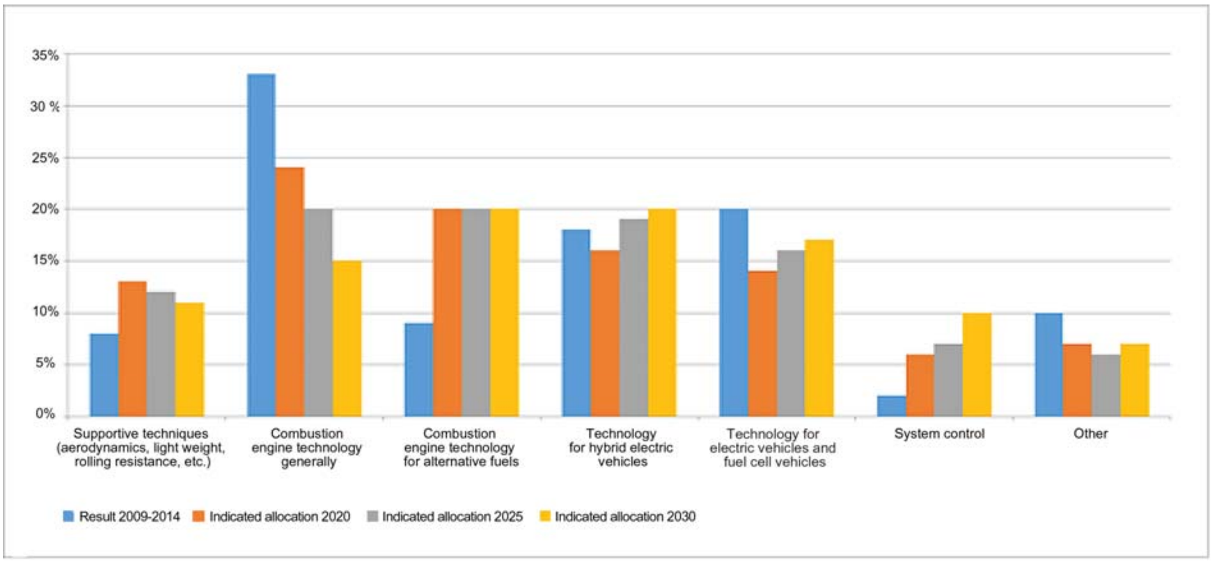
Share of traffic, % of total number of vehicle kilometres driven on electric

	2020	2025	2030
Sweden*	0%	<1%	1%
Other countries	0-5%	0-5%	1-20%

5.3.2 Milestones for FFI Energy and environment, Haulage vehicles

	Milestone 2020 On the market 2023-2025	**Milestone 2025** On the market 2028-2030	**Milestone 2030** On the market 2033-2035
Milestone CO_2 emissions (% lower CO_2 emissions/tonne kilometre compared with base year 2008) (energy efficiency + alt. fuel)	65%	80%	"100%"
Milestone Energy Efficiency (% lower kWh/person kilometre compared with base year 2008)	25%	30%	>30%
Milestone Noise (certified level at the vehicle)(Swedish Transport Administration's estimate)	77 dB	74 dB	72 dB
Milestone Other emissions	European requirements that are increasingly met in real traffic throughout the life of the vehicle and for all certified fuels		
Emphasis on research	Active control of streaming flow to reduce streaming losses	Electric hybrid power trains with efficiency-adapted electric and internal combustion engines powered by electricity/alt fuels.	Electric hybrid power trains with efficiency-adapted electric and internal combustion engines powered by electricity/alt fuels.
	Euro VI engines that are energy efficiently powered by alternative fuels	Adaptation to electrified roads	Electrified roads, hAutonoma vehicles for minimised energy use
	Internal combustion engines and transmissions with lower noise levels	Power train development for vehicles with greater load capacities	Hybrid systems with alternative battery solutions, including fuel cells

5.3.3 *2015 Indicated allocation of research funding in % within the FFI Energy and environment for haulage heavy vehicles per technology area and period*



The FFF report indicates that in the longer term electric hybrid trucksin long-distance traffic can be an alternative to trucks with conventional power trains. In this case, it would involve some type of direct transmission of electricity to the lorry, which requires expanded infrastructure. There are several different proposals for technologies for transfer electricity, some of which would also allow passenger cars to use the system, which would also extend the range of electric cars considerably.

Up to 2030, the FFF report expects 1 per cent of heavy haulage traffic could be electrified. For example, 25 per cent of Swedish heavy goods traffic is on the 1000-kilometre-long triangle Malmö, Gothenburg, Jönköping, Stockholm, Malmö. Up to 2050, the report expects 25 per cent of lorry traffic in Sweden to run on electricity.

Most future scenarios expect long distance freight transport to increase similarly to GDP growth. Even with the transfer of goods transport to the railway network and effective inter-modality between modes of transport, road freight transport will be responsible for a significant increase in volume during the period up to 2030. Vehicles adapted to the transport system's requirements are therefore crucial. The strategy to achieve this improvement follows 3 main approaches:

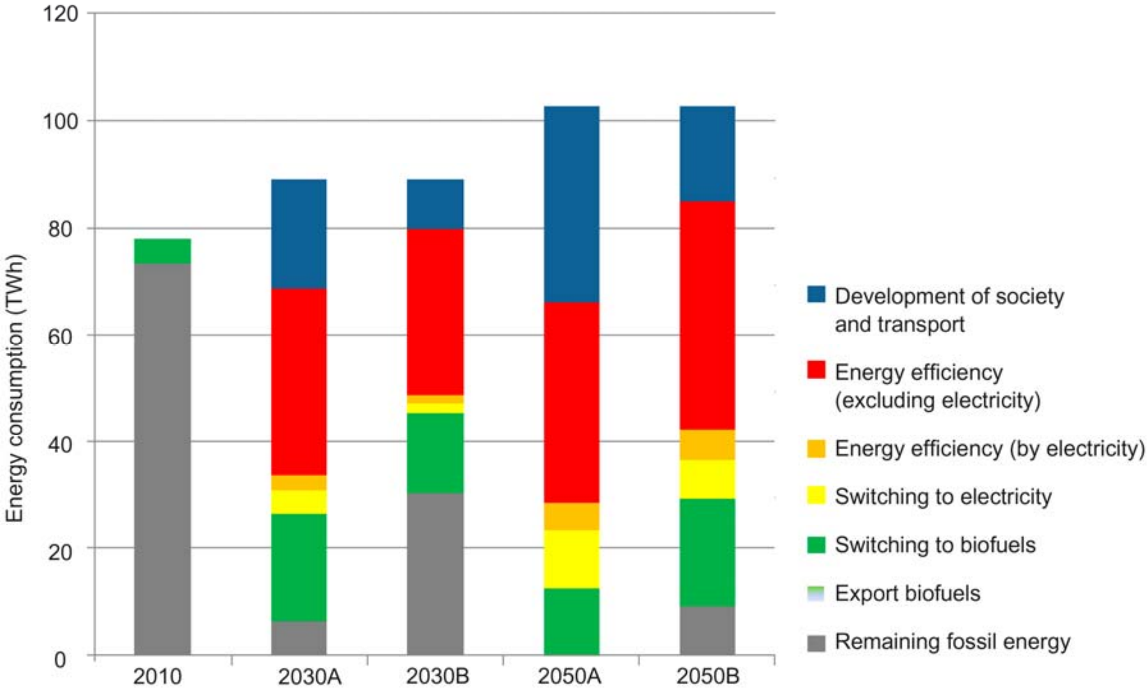
- Efficient vehicles through reduced energy losses
- Efficient power trains through increased efficiency
- Effective drivers through training and feedback from the vehicles

At the complete vehicle level, it is important to be able to adapt the vehicle to its task. Other aspects include aerodynamics, effective assistance systems, reduced rolling resistance and light weight concepts. Liquid fuels are expected to be the main option for power trains in the period up to 2050 but engines must be adapted to alternative renewable fuels that are expected to take a gradually larger share of the market.

Safe access to standardised and qualitative alternative fuels that give operators a problem-free and economically viable alternative to conventional fuels is a prerequisite for establishing demand for heavy road transport vehicles that are powered by alternative fuels. Only then can a gradual increase in the proportion of alternative fuels on the road be accomplished for this type of traffic.

Efficiency improvements on the power train are accomplished primarily by highly efficient combustion with optimal control, brake energy recovery, minimising use of low-efficiency operating points for the internal combustion engine and systematic work to reduce friction. For the period up to 2020, power trains, tyres and aerodynamics are expected to be responsible for the majority of the improvements. For 2025 and 2030, aerodynamics and control of energy become increasingly important. The driver's behaviour also represents a significant potential for fuel savings. More and more effective support systems from eco-driving to semi-autonomous systems are likely to evolve. In the longer term, continuous transmission of electricity from the road may be an option.

Road traffic use of fossil energy with and without measures (TWh). The top of the stacks reported progress



without measures ie Today projection, the gray fields remaining fossil energy for action. Negative values relate to the export of bioenergy

***Table 2** is taken from the report Fossilfrihet på väg [Fossil independent transport sector] and shows the importance of energy efficiency improvements and alternative fuel in the potential to reduce carbon dioxide emissions from road transport in the future. This is particularly clear in respect of heavy haulage where completely electrified vehicles are not likely a possible option because of battery weight and size.*

The vehicles referred to are trucksintended for long-distance transport. Distribution trucks are expected to have a higher degree of hybridisation/electrification. Longer vehicles are likely to increase the efficiency of the transport of volume cargoes. Heavier vehicles with a load capacities of almost 90 tonnes are also expected to become a reality, depending on road standards. For vehicles with extreme start/stop characteristics, such as refuse collection vehicles, power train development will be similar to those for city buses, i.e. a very refined hybridisation/electrification.

The introduction of hybrid technology on vehicles for long distance traffic will primarily depend on the cost level for the electric power train and energy storage. Incentives that enable an increased volume and therefore a reasonable cost level of these subsystems are important for market introduction.

Quieter vehicles are a requirement from society. Maximum permissible noise levels have been reduced in several steps during the period 2020 to 2030. Development of quieter engines, transmissions and tyres will be carried out at a time when the combination of these and noise absorbers is necessary to cope with society's increasing noise requirements during the period. Local noise requirements can push demands for electrified vehicles and thus also contribute to CO_2 reduction.

6 Conclusion

The roadmap is for the programme committee a common instrument for strategic choices relating to research and development and that it will be valuable in following up the programme as well as conveying an overall picture of FFI and its importance for the Energy and environment area. The roadmap will need to be updated regularly, probably at least every two years.

This document contains examples of areas of research and development that are relevant to the FFI programme within the area Energy and environment. This should not, however, be interpreted as though these are the only areas where FFI can fund “strategic vehicle research, development and innovation activities”.

7 Follow-up

The programme’s activities will be evaluated to ensure compliance with the project's general requirements concerning programme-specific objectives.