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HTSM Automotive Roadmap 2020 - 2030

Preamble

The Dutch Automotive Industry accounts for one of the largest export volumes in the Netherlands. About 20 billion annually. In a country with a high cost-structure like ours, this can only be achieved by delivering world-class technology. World-class technology is based on world-class knowledge. And that is what we are working on, every day. Not only at DAF Trucks, but also together with the Dutch Automotive Community. The Automotive Industry is one of the cornerstones of the High Tech Systems and Materials sector. A car or a truck is a remarkable High Tech System. Easily equipped with over 30 micro-processors, a high-tech Internal Combustion Engine with sophisticated after-treatment system, Fuel-cell , Battery-pack. You name it. It delivers you or your cargo in a sustainable, fast, safe, reliable, cost effective way to where ever you need.

Since you are related to the Automotive Industry you know the challenges we are facing the coming decades. With CO2-reduction being by far the most important at this moment for many of us. Where local air quality and traffic safety, in particular regarding vulnerable road users, are top priorities for our society as well. But also with inevitable digitisation impacting our products and business in an unprecedented way. All of this are the ingredients for a complete new Automotive Roadmap, that will be released today. As Chairman of the Automotive Roadmap working group, I can not stress enough the importance of the focal points addressed within this Roadmap for the position of the Dutch Automotive Industry, but also for achieving important societal goals. Subjects like hydrogen as direct fuel for HD combustion engines, HD hybrid drivetrain technology and battery and battery-pack technology are of great importance but also sensing, driver assistance and navigation technology that come from our Dutch industry.

We as a company take the lead in many of these subjects. But we would like to cooperate with Dutch partners in these innovations, although we of course have to look beyond the border. We also count on cooperation with the Dutch government in achieving these very demanding Roadmap challenges.

I hope you get inspired by the new Automotive Roadmap.

Ron Borsboom

Chairman HTSM Automotive Roadmap Team

Colophon

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Legal Mentions

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Revision Index

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1. Introduction

The HTSM Automotive Roadmap 2020 – 2030 is succeeding the HTSM Automotive Roadmap 2018 – 2025. The reason for this is the creation of the Klimaatakkoord and the 'Meerjarige Missiegedreven Innovatieprogramma Duurzame Mobiliteit 2020-2024'. The objectives from the Climate Agreement to reduce CO2 emissions from mobility to a maximum of 25 Mton by 2030 (7 Mton lower than the current situation) and to be reduced to almost zero by 2050 require acceleration of plans.

The Dutch "Top sector Policy" applies to key economic areas (the top sectors[1]). For these areas, a national approach of smart collaborations between industrial parties, research institutes and academia (universities), and the government has been defined. Within this so-called Triple Helix innovation framework Roadmaps have become the focal points in guiding Research and Development (R&D) within the "Top sector Policy". The subsequent document relates to 'Automotive Industry' as a part of the top sector "High Tech Systems & Materials" (HTSM).

The top sector High Tech Systems and Materials (HTSM) is an important contributor to the Dutch economy, driving technological developments and so is the automotive industry. The automotive industry develops and applies technologies that can make a vital contribution to the Dutch economy and the societal challenges in the decade(s) ahead.

The primary audience for this document includes Automotive Industrial stakeholders (OEM[2] and TIER[3] suppliers), research institutes and educational stakeholders, regional governments and the ministries of Economic Affairs and Climate Policy, Infrastructure and Water Management, Finance and Foreign Affairs.

1.1   Goal and Scope

The main goal of this HTSM Automotive roadmap is to provide a joint stakeholder view on the R&D needs of the Dutch automotive sector up to 2030, More precisely, this roadmap aims to provide guidance for (i) the industry and its stakeholders for developments and (ii) the government for their supportive strategy to meet the needs of the next decade.

Figure 1: Context and scope of HTSM Automotive roadmap

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[1] https://www.rvo.nl/onderwerpen/innovatief-ondernemen/topsectoren
[2] Original Equipment Manufacturer
[3] Suppliers within the manufacturing chain

Whilst the focus is on "future on-road vehicles", other modalities can also benefit from the sector's innovations. Due to the international playing field of the automotive sector, these vehicles are studied in a national as well as European context. Within the European context, the EC ambitions stated in its Mobility Packages[4][5], are relevant to both Smart and Green mobility, as well as their intersection.

The automotive industry sector is a global market and companies all over the world are competing in solving the societal issues. Within the European context, the EC ambitions stated in its Mobility Packages[6][7], are relevant to both Smart and Sustainable (Green) mobility, as well as its intersection. On national level, the Climate Agreement together with the associated Multi-year Mission-orientated Innovation Program (MMIP) on Sustainable Mobility[8] and Integral Knowledge and Innovation Agenda (IKIA) on climate and energy[9] give clear directions in terms of focus areas for future-proof mobility systems:

1. Behavioural change and social structures;
2. Digitization and platforms;
3. Making vehicles sustainable;
4. Next generation battery technology;
5. Energy carriers and engines;
6. Smart mobility and logistics.

This HTSM Automotive roadmap is directly connected to the focus areas 2, 3, 4, 5 and 6. Based on the current status of vehicle technology and on the challenges to reach the ambitious goals associated with future Sustainable and Smart mobility, this roadmap identifies the key technology development lines. By enhancing their technology position, the selected pathways strongly contribute to the competitiveness of Dutch companies in the automotive sector.

A strong cooperation between industry, knowledge institutes and government in the automotive field as well as its correlation to other relevant roadmaps (See EU A.3.1 and HTSM A.4.1) is deemed vital for the future success of this roadmap and the Automotive sector. This requires a holistic approach. Therefore, besides technology development, also essential development in enabling fields, such as education and facilities, are discussed.

1.2   Audience

The primary audience for this document includes Automotive Industrial stakeholders (OEM[10] and TIER[11] suppliers), research institutes and educational stakeholders, regional governments and the ministries of Economic Affairs and Climate Policy, Infrastructure and Water Management, Finance and Foreign Affairs.

A stakeholder summary, as an extract of this document is also available.

1.3   Document outline

This roadmap document is organized as follows:, As Chapter 1 introduces the document and its structure, Chapter 2 provides an overall summery of the detailed content of the roadmap, providing high level guidance and indicating focus area's .To sketch the context, first the main drivers and challenges for future on-road vehicles are briefly reviewed in Chapter 3. This sets clear targets for technology development. In

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[6] https://ec.europa.eu/transport/sites/transport/files/mobility-package-factsheet-iii.pdf
[7] https://ec.europa.eu/transport/sites/transport/files/mobility-package-factsheet-iii.pdf
[8] Meerjarige Missiegedreven Innovatieprogramma Duurzame mobiliteit, https://www.klimaatakkoord.nl/documenten/publicaties/2019/11/07/mmip-9-en-10-emissieloze-mobiliteit
[9] https://platformduurzamebiobrandstoffen.nl/wp-content/uploads/2020/04/2019_Klimaatakkoord_Innoveren-met-een-missie-IKIA-integrale-kennis-en-innovatieagenda-voor-klimaat-en-energie.pdf
[10] Original Equipment Manufacturer
[11] Suppliers within the manufacturing chain

addition, future vehicles are placed in the wider context of cross sectorial technology trends in Chapter 4. This illustrates that future vehicles are part of large transport, energy and information ecosystems. In order to focus technology developments, boundaries and key research areas are specified for this roadmap. For these research areas, relevant technology trends for smart and green mobility are presented in Chapter 5. Based on this information, the key technology development lines are identified and are described in more detail in Chapter 6. Finally, essential enablers for this technology roadmap, including facilities and education, are discussed in Chapter 7.

2. Management Summary

2.1 Introduction

The Automotive sector is facing major challenges. National and international agreements with regard to sustainability, such as the EU climate agreement, social trends and international competition require smart and sustainable mobility. The impact of the corona pandemic on the manufacturing industry and in particular the Automotive industry, is an additional obstacle. Therefore, investing in innovation is a top priority for the Dutch automotive industry to maintain a strong international position and to overcome the COVID-19 related economic downturn.

Drivers for innovation in the Dutch Automotive sector are the shared ambitions to achieve zero fatalities and zero emissions in road transport. The themes Sustainable Mobility and Smart Mobility are the building blocks to achieve this. Major steps are already being taken at various levels in the Netherlands when it comes to making the Automotive sector more sustainable. Closer cooperation and mutual goal setting between parties within the sector can therefore lead to an acceleration of this transition. The goal of this HTSM Automotive roadmap provides a joint stakeholder view on the priorities in R&D needs up to 2030.

Sustainable Mobility and Smart mobility and mobility have become more and more related to each other. Green Mobility focuses on development strategies related to the delivery of power to the wheels from an energy source (tank-to-wheel). The ambition is to reach zero emissions in road transport.
Smart Mobility is divided in four subthemes; Cooperative Driving, Automation, Connectivity and Smart Mobility Services. In the near future, especially the first three themes are likely to come together and combine functionalities to enable Automated Driving. Driver for innovation is to achieve zero fatalities in road transport. In the roadmap both green & smart mobility have sec a vehicle focus. Manufacturing and the Automotive learning community, both addressed in this document, are crucial enablers.

2.1 Economic role of the Dutch Automotive Industry

The Netherlands is the sixth largest economy in the European Union and is the 17th-largest economy in the world[12]. The Netherlands has a long history of innovations and as such it is globally recognized as an important knowledge generating country[13]. The present societal challenges stimulate the Dutch innovation strength and solutions create new products, manufacturing methodologies and services in the global market.

Within the Dutch automotive industry, roughly[14] 45,000 people are employed, of which 10,000 at OEM's, 4,000 in manufacturing special vehicles and trailers, 29,000 at Tier-suppliers and 2,000 working in research and knowledge institutes (See Figure 2). The export volume amounts € 20 billion per year. The Dutch automotive industry consists of more than 300 companies. About 200 of them are united by their membership of RAI Automotive Industry NL**[15]**, which is the Dutch cluster organization representing the automotive industry on a national and international level .

[12] https://www.investopedia.com/insights/worlds-top-economies/
[13] Automotive bijv Rland Berger and KPMG
[14] https://opendata.cbs.nl
[15] https://www.raivereniging.nl/automotiveindustrynl
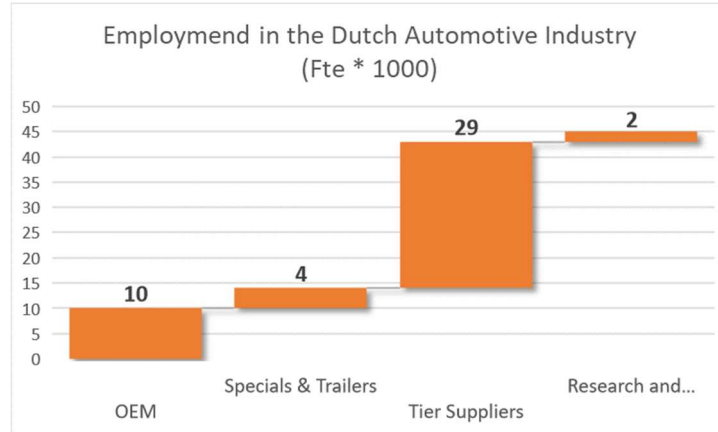
Figure 2. Employment Dutch Automotive Industry

The Dutch automotive industry consists of more than 300 companies. About 200 of them are united by their membership of RAI Automotive Industry NL[16], representing the automotive industry on a national and international level. The export volume amounts € 20 billion per year, about 88% relates to export of which Germany is consuming the largest share (Figure 3 below).
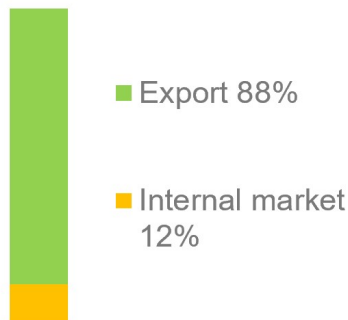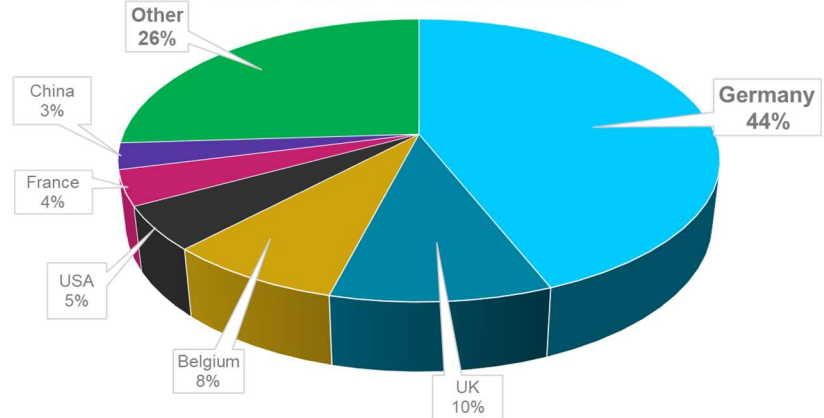
Figure 3. Turnover and export Dutch Automotive Industry

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[16] https://www.raivereniging.nl/automotiveindustrynl

2.2 Transformation of the Automotive Sector

The Automotive sector is facing major challenges. Next to the societal trends, challenges are national and international agreements with regard to sustainability. The impact of the corona pandemic on the manufacturing industry and in particular the Automotive industry, is an additional obstacle. Therefore, investing in innovation is a top priority for the Dutch automotive industry to maintain a strong international position and to overcome the economic downturn.

The sector worldwide is on the eve of a major transition to a sustainable, smart and safe mobility system. Due to the growing population, accessibility is under pressure. In terms of road safety, the ambition of zero road casualties is not in sight. And CO_2 emissions in the transport sector have grown instead of decreased since 1990, which puts additional pressure on achieving the climate targets (Transport delta).

The Netherlands is well prepared to occupy a leading position here. In addition to market leaders such as DAF, NXP, VDL, TomTom and Bosch Transmission Technology, the Netherlands has a strong position and players in the field of navigation / localization (TomTom, HERE, MapScape / NavInfo) and software / smart infrastructure (Van der Lande, Prime Vision, Dynniq, Vialis and Siemens). These players are surrounded by a wide supply chain to SMEs and innovative startups and scale-ups (Green & Smart Transport delta)

Transitions as disruptive as needed for the transport sector require huge investments and strong cooperation between industry, knowledge institutes and government. The amount of investments is at least comparable with the amount of money of innovation programs such as the green and smart transport delta.

Furthermore we'll have to look to other countries ambitions. Especially in Germany and France huge investments are made to meet future requirements.

2.3 Cross-sectoral context

A strong cooperation between industry, knowledge institutes and government in the automotive field as well as its correlation to other relevant roadmaps is deemed vital for the future success of this roadmap and the Automotive sector. This requires a holistic approach. Therefore, besides technology development, also essential development in enabling fields, such as education and facilities, are discussed.

Furthermore, there is a strong link to the energy and logistics topsectors as enabling technologies and context for developments in both green and smart mobility and sustainable manufacturing. There are interfaces with the energy TKI sectors energy and industry, digitalization and the human capital agenda. Within te Logistics Topsector, strong links are with city logistics, sustainability and the human capital agenda. Within the HTSM domain, the automotive roadmap is interconnected with the following HTSM roadmaps:

- Business Cluster Semiconductors
- Photonics
- Embedded Systems
- High Tech Materials
- Smart Industry
- Solar
- Components & Circuits

2.4 Sustainable Mobility

In the upcoming decades, the automotive industry faces enormous challenges to contribute to climate neutral mobility in 2050. For the short term, tailpipe CO_2 emissions from passenger cars as well as heavy-duty vehicles have to be reduced by 30% in 2030 (compared to 2019). Simultaneously, very challenging real-world pollutant targets have to be met and various European cities announced the introduction of zero emission zones by 2030.

To realize the required, massive reduction levels, an integrated system approach is required. Besides changes in human behaviour, a combination of logistical, traffic and vehicle measures is needed. From a cross-sectoral, well-to-wheel perspective, it is essential that future vehicle technologies also support the energy transition by enabling the use of sustainable energy carriers. Currently, there is general consensus that there is not one single energy transition pathway towards sustainable mobility. To meet future decarbonization targets at lowest possible cost, all energy carriers that can contribute will be needed. Three pathways are considered to be most promising for mobility:

- Renewable electricity,
- Renewable hydrogen and
- E-fuels (or power-to-X).

For passenger cars, a clear shift towards battery electric vehicles (BEV) is picking up, but also fuel cell vehicles (FCEV) are foreseen. A similar shift will take place for city distribution and bus applications. Internal combustion engines (ICE) will remain the primary power source for future heavy-duty powertrains in the upcoming decades. To meet requirements for zero emission zones, hybridization of ICE-based powertrains will play an important role.

Based on these trends, five research priorities are identified in this HTSM Automotive roadmap. These research priorities are important for the Dutch automotive industry to strengthen its economic position and to accelerate developments that contribute to the missions specified in the national knowledge and innovation agenda. These priorities are robust for possible shifts in the energy mix and for changing focus on energy carriers. First, battery technology is crucial for all pathways in the energy transition; new generation battery systems are required to enhance energy density, cost efficiency and durability. Second, for ICE-based concepts, highly efficient combustion concepts that enable a wide range of E-fuels are key. Besides application of carbon-based E-fuels, also hydrogen (H_2-ICE) is attracting increasing attention as a zero (tailpipe) CO_2 emission solution. Third, there is a need for modular, highly efficient powertrain components and systems for all powertrain concepts. In addition, important enabling technologies are smart vehicle energy management and geofencing to maximize real-world performance within emission limits and advanced development tools to minimize development time and costs.

Besides the research priorities, related topics are identified:

1. **Societal driven priorities:**
   - Contribute to the Vision Zero aims: no road mobility fatalities;
   - Tackle safety challenges from new mobility concepts, including challenges for vulnerable road users;
   - The increasing call for urban transitions: more shared space, less car focussed street occupation;
   - Optimisations to include human behaviour in changing conditions, including transition of control;
   - Address the operational needs and opportunities to increase efficiency, flexibility and reduce travel time and costs;
   - Include the vehicles in the traffic flow combined with active modes of transport, with many interactions.

2. **Technology focussed priorities**:
   - Driving in mixed traffic conditions, with road users equipped and not-equipped with connected and/or automated vehicle functions;
   - Develop advanced safety functions and human centred Advanced Driver Assistance Systems (ADAS);

- Define and develop the essential digital and physical infrastructure to enable large scale deployment of smart mobility solutions;
- Extend the Operational Design Domain of ADAS and autopilot, make clear steps beyond the use in confined areas;
- Development of understandable, explainable and trustworthy AI solutions to further boost the smart mobility developments;
- Develop and use assessment tooling and facilities, including digital twins of physical infrastructure, supporting the development, validation, assessment and monitoring automated driving functions;
- Further developments on radar technology and other perception system related technologies.

2.5   Smart Mobility

Safety challenges from new (multi-modal and/or shared) mobility concepts need to be tackled for all road users including vulnerable road users and users of new vehicle types. The aim to achieve zero casualties is the main driver for the activities in the field of Smart Mobility.

The automotive industry is undergoing the initial phase of a transition from vehicle provision towards provision of mobility. Accessible, inclusive and affordable mobility for all will become a huge challenge in the coming decades. The need for less congestion, especially in cities, the changing infrastructure enabling mass transit as well as active modes of transport much more than before and the sharing economy are playing an important role in this transition. In this transition, mobility and transport will become more and more smart[17].
Missie D+ , MMIP 9, 10 and especially the 'deel Kia Toekomstbestendige Mobiliteitssystemen' give directions to this transition and the underlying development needs. For the activity field of Smart mobility the main challenge is to develop and implement systems which maximally address the social drivers (safety, environment and throughput), making efficient use of the possibilities offered by e.g. digitalization and automation in relation to robustness, security and redundancy.

The four subthemes (Cooperative Driving, Automated Driving, Connectivity and Smart Mobility Services) are linked and their developments go hand in hand. For next stages of the developments, **cross sectoral cooperation with e.g. urban planners and telecom industry will be needed**. The connectivity enables data transfer, data storage and data sharing as part of the ongoing digitalisation of mobility. Cyber security and AI are emerging topics, as well as connecting the individual mobility needs to the overall mobility system; an optimisation for both, in a balanced way, needs to be established.
Several Dutch cities and regions are willing to open up their infrastructure to test and trial new mobility solutions. Discussions on Physical and Digital Infrastructures and Operational Design Domains of new vehicles show the need for close collaboration between the automotive industry and (regional) road authorities. Main issues currently are:

3. **Societal driven priorities:**
   - Contribute to the Vision Zero aims: no road mobility fatalities;
   - Tackle safety challenges from new mobility concepts, including challenges for vulnerable road users;
   - The increasing call for urban transitions: more shared space, less car focussed street occupation;
   - Optimisations to include human behaviour in changing conditions, including transition of control;
   - Address the operational needs and opportunities to increase efficiency, flexibility and reduce travel time and costs;
   - Include the vehicles in the traffic flow combined with active modes of transport, with many interactions.

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[17] The document mostly speaks of Smart Mobility. It inherently includes mobility of people and transport of goods.

4. **Technology focussed priorities**:
- Driving in mixed traffic conditions, with road users equipped and not-equipped with connected and/or automated vehicle functions;
- Develop advanced safety functions and human centred Advanced Driver Assistance Systems (ADAS);
- Define and develop the essential digital and physical infrastructure to enable large scale deployment of smart mobility solutions;
- Extend the Operational Design Domain of ADAS and autopilot, make clear steps beyond the use in confined areas;
- Development of understandable, explainable and trustworthy AI solutions to further boost the smart mobility developments;
- Develop and use assessment tooling and facilities, including digital twins of physical infrastructure, supporting the development, validation, assessment and monitoring automated driving functions;
- Further developments on radar technology and other perception system related technologies.

2.6   Sustainable and Smart Manufacturing

The automotive industry is shifting from traditional production towards sustainable and smart manufacturing. This means that production methods/processes, natural resources and energy sources are in the process of optimization and adapting new technologies in order to contribute to environmental, social and climate related themes.

The business climate for the Dutch Automotive Industry has developed over the past decades from regional to European and even global. The current playing field is an international industry where companies must deal with international competitors, customers and suppliers and their challenges. An issue today, which will remain in the future, is fluctuating demand from a more diverse customer base. This forces companies to include a higher level of flexibility in their manufacturing process. In addition, manufacturing companies are faced to reduce CO_2 emissions and introduce circularity, driving a growing awareness of strategical adaptations to remain competitive. Future prospects and the development of high-quality, sustainable (incl. circularity) and smart (incl. Big data and AI) production are actual trends.

In addition, depending on the development of various mobility concepts, we may see trends such as; maximum production volume flexibility and low cost high volume production lines. Whilst adding value is and remains an absolute necessity to make sufficient margin.

COVID-19 teaches us that reliance on supply chains outside the EU can be risky and EU supply chains may offer more stability. Products will also imply a strategy for future disassemble, refurbish and recycle as part of a product life cycle. Sustainable and smart manufacturing is strongly interconnected with the Roadmaps High Tech Materials and Smart Industry.

2.7   Automotive Learning Community

In order to make sustainable and smart innovations pay off quickly in practice, companies and education will have to team-up quickly and people must be adequately trained and equipped with the state of the art technology.

As such, learning instruments and training facilities will be integral part of R&D and pre-deployment. Digital twins, big data and artificial intelligence (AI) are key enablers for efficient and smart mobility, directly related to the Engineers of the Future.

The goals of the relevant human capital activities are related to two aspects:
1. **Quantity**: Sufficient numbers of "Engineers of the future" at all levels.
2. **Quality**: Education programs based upon the future needs of the industry.

3. Drivers and Challenges

In order to define the required automotive technology developments, it is essential to understand the context and requirements for smart and sustainable mobility. Therefore, first the main drivers and challenges for future on-road vehicles are briefly reviewed in this section. More precisely, the key targets for future on-road vehicles are specified.

3.1 Societal challenges and trends

Affordable and easily accessible transport of people and goods is a key element of today's modern society. Its importance is expected to further grow in the future[18]. Driven by societal concerns related to air pollution, global warming, accessibility of cities (zero emission zones and geo-fencing) and traffic safety, there is consensus on the long-term goals set for the various international research agendas and programs:

<p style="text-align:center;">**Zero emission and Zero Accidents in 2050**</p>

To support these ambitions, a comprehensive European strategy on sustainable and smart mobility will be defined[19]. This strategy aims to realize important contributions to climate-neutral mobility in 2050[20] and to ensure safety and accessibility while exploiting digitalization, automation and connectivity[21] [22]. In the next sections, the national as well as European trends and targets set for the transport sector are discussed in more detail. Focus is on environmental, energy, safety and accessibility topics.

3.1.1 Global warming and air quality

For the upcoming two decades, increasingly strict greenhouse gas (GHG) emission legislation will be the key driver for technology developments in the automotive sector. Simultaneously, very challenging real-world pollutant targets have to be met and zero emission zones in and around cities will be introduced.

3.1.1.1 Reduction of greenhouse gas emissions

The transport sector has to contribute significantly to operationally reduce greenhouse gas emissions. This is illustrated in Figure 4. For this sector, the European Commission defined a 60% reduction target of GHG emissions in 2050 relative to the year 1990[23]. This is in line with the targets as set in the COP21 Paris agreement [AD-1] and forth coming the Dutch National agreement [AD-2] to limit the increase in global average atmospheric temperature to 2°C. However, there is more and more awareness that ca. 90% CO_2-reduction is even needed to strive for maximal 1,5 °C temperature increase. For Europe, these new, long term ambitions are recently formulated in the European Green Deal, which target net greenhouse gas (GHG) towards zero emission by 2050.

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[18] https://mobiliteitsalliantie.nl/wp-content/uploads/2019/06/Trends-en-ontwikkelingen.pdf

[19] https://ec.europa.eu/transport/themes/strategies/news/2020-02-03-commissioner-valeans-speech-eu-strategy-mobility-and-transport_en

[20] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[21] https://ec.europa.eu/transport/themes/strategies/news/2020-02-03-commissioner-valeans-speech-eu-strategy-mobility-and-transport_en

[22] https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

[23] White paper, https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en
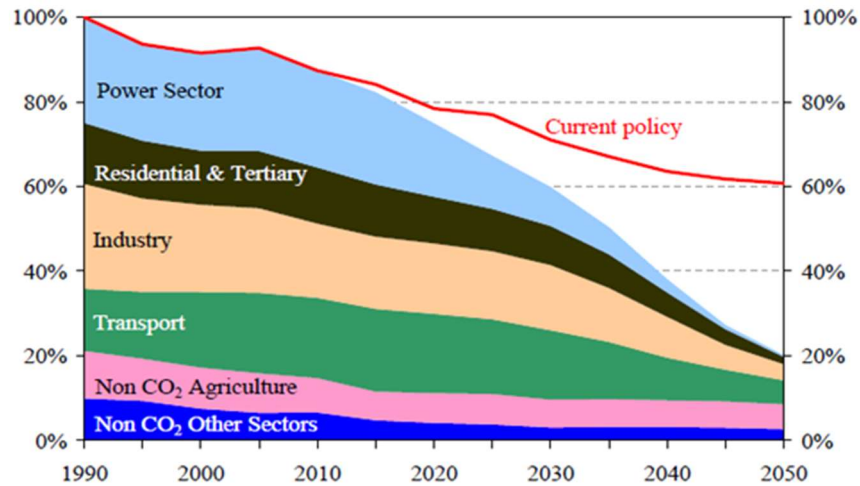
Figure 4. EU GHG emission towards 2050 [24]

To regulate GHG emissions, European legislation concentrates on CO_2 emissions, as summarized in Figure 5. Up to 2030, vehicle manufacturers have to meet concrete emission targets. For passenger cars, the fleet-average target for new vehicles is 95 g CO_2/km in 2021. Additional reductions of 15% and 37.5% are required for 2025 resp. 2030.
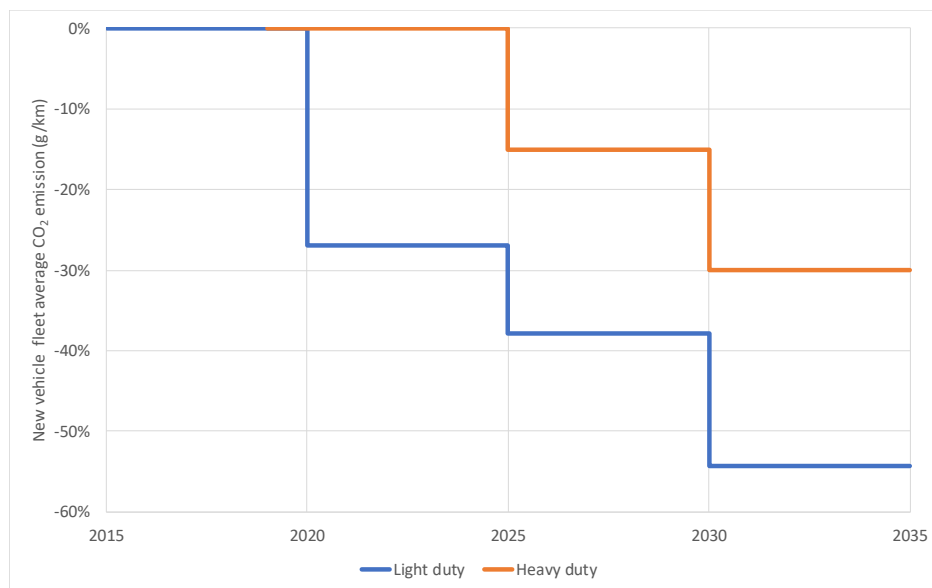
Figure 5: Overview of European GHG emission legislation for light-duty and heavy-duty vehicles

For heavy-duty applications, such as trucks and buses, European CO_2 emission targets have recently been defined. Compared to the 2019 baseline, the new vehicle fleet-average CO_2 emissions have to be reduced by 15% in 2025 and by 30% in 2030. Note that these CO_2 targets are specified on vehicle level: tailpipe CO_2 emissions (in g/km). To enable this legislation the Vehicle Energy Consumption Calculation Tool (VECTO)[25] was developed, as a whole vehicle type approval test was considered not feasible and appropriate for HD vehicles. Using this vehicle simulation tool, CO_2 emissions from heavy-duty vehicles of different categories, sizes and technologies are estimated; provided that the technology is represented within the tool. This

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[24] Communication from the Commission to the European parliament, A roadmap for moving to a competitive low-carbon economy in 2050

[25] https://ec.europa.eu/clima/policies/transport/vehicles/vecto_en

approach stimulates the heavy-duty sector to consider a whole vehicle approach; innovations around powertrain, truck and trailer are expected. Both the LD ad HD CO_2 legislation also promote the introduction of vehicles with zero emission propulsion systems.

3.1.1.2   Towards zero impact pollutant emissions

In addition to the increasingly strict CO_2 emission targets, vehicles also have to contribute and meet challenging targets related to air quality. To mitigate the effects of pollutant emissions on human health and the environment, governments introduced legal emission standards to regulate emissions from combustion engines, especially nitrogen oxides (NO_x), particulate matter (PM), hydrocarbons (HC) and carbon monoxide (CO). Since the introduction of increasingly stringent emission limits, pollutant emissions from internal combustion engines have been dramatically reduced over the last three decades. This not only holds for approval tests in the laboratory, but since Euro 6/VI also on the road. This is mainly due to increasing attention for real-world emissions, the inclusion of real-world driving tests using Portable Emission Measurement Systems (PEMS) in the type approval legislation, and to more extensive monitoring of on-road performance. Additionally, future standards are expected to address previously unregulated emissions (e.g. ammonia, formaldehyde, nitrous oxides etc.), as well as further steps towards On-Board Monitoring.

In the near future, the operating window for real-world testing is expected to be further enlarged: wider range of ambient temperature and altitude and of load conditions. In addition, more attention will be paid to maintaining low emissions over the entire lifetime of the vehicle. This includes effects of ageing as well as of tampering. Moreover, with the increasingly strict particulate number emission levels for internal combustion engines, there will be an increasing focus on particulate emissions from brakes and tires. Meanwhile, there will be increasing focus on smaller particles from the engines themselves.

Finally, consideration and regulations around nitrogen emission levels (NVM) and Electro Magnetic (EM) emission levels will be equally prevalent around future vehicle design and regulation.

3.1.1.3   Zero emission zones

Besides European emission legislation, an increasing number of initiatives at the national, regional and local level are introduced to improve local air quality. As a first step, many European cities introduced low emission zones, allowing only vehicles that meet strict emission standards. As a next step, various European cities announced the introduction of zero emission zones by 2030. On national level, the Climate Agreement[26] set out key actions to support the European Green Deal[27], including policy intention that 30 to 40 larger municipalities in the Netherlands introduce zero emission zones for city logistics by 2025. Also, zero emission construction traffic and mobile machinery is a target for 2030.

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[26] https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/06/28/national-climate-agreement-the-netherlands/20190628+National+Climate+Agreement+The+Netherlands.pdf

[27] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_nl

3.1.2 Transition towards sustainable energy carriers

To realize climate-neutral mobility and transport in 2050, it is crucial that future solutions enable the use of sustainable energy carriers. This includes renewable electricity, renewable hydrogen and renewable carbon-based fuels. This is in line with the EU Renewable Energy Directive[28], which sets an overall EU target for renewable energy consumption of 32% in 2030. For transport, this directive includes an additional sub-target of minimal 14% renewable energy for fuel suppliers to road and rail transport. On a national level, the Climate Agreement mentions the following related key areas for 2030: renewable energy suppliers, stimulation of hydrogen and ambition for 100% new zero-emission cars. Figure 6 illustrates a possible transition pathway.

2020 — 2050

■ Diesel ■ Bio-Diesel ■ Natural Gas ■ H2 ■ Electric ■ Bio Natural Gas ■ E-Fuel, Sun-Fuel
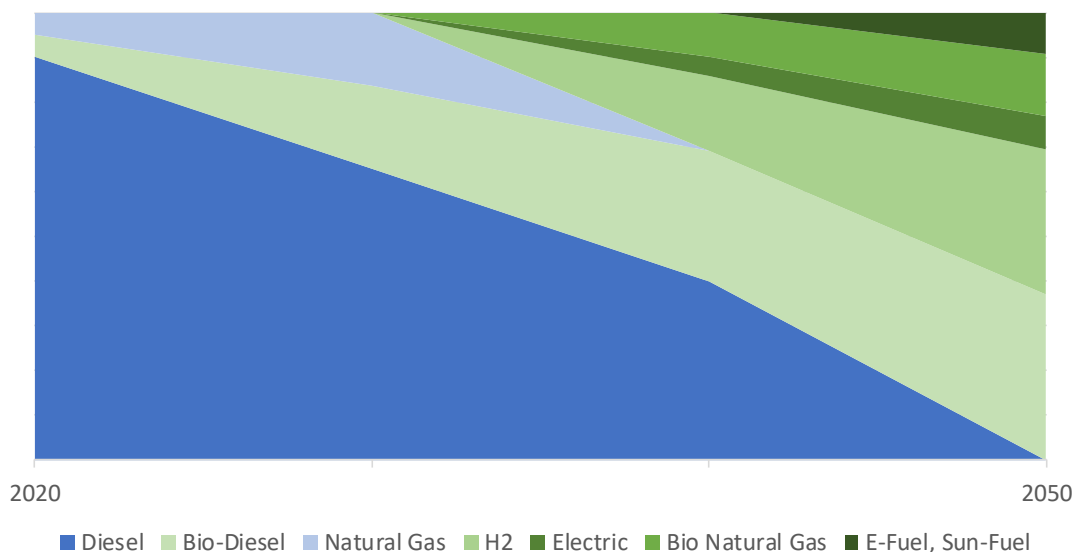
Figure 6: Illustration of possible transition pathway towards renewable energy carriers

In order to reach the ultimate goal, renewable energy carriers only in 2050, a well-planned and economically viable pathway is needed. This is due to (i) the need for affordable renewable energy production; (ii) the required time and investments to realize a large-scale infrastructure (and the corresponding effect on well-to-wheel CO_2); (iii) the competition from various sectors for sustainable molecules and energy carriers, especially biomass and green electricity and hydrogen; iv) the need to avoid technology lock-in.

For passenger cars, city distribution and busses, a rapid growth of electric solutions is foreseen in the upcoming decade. Also, hydrogen-based solutions become important. For heavy road transport, on the other hand, liquid fuels will remain the main energy carrier due to their compatibility with existing infrastructure and superior energy density. For the period up till 2030, the standard liquid fuels (diesel, gasoline) and alternative fuels (natural gas, biofuels) can be made available in sufficient amounts. This is supported by the EU Renewable Energy Directive that set targets for biofuel use and by the realization of LNG infrastructure along the main European transport corridors in response to the Alternative Fuels Infrastructure Directive. In the transition phase towards a situation with renewable energy carriers only, the importance of sustainable biofuels/bio-LNG and renewable synthetic fuels will grow, as illustrated in Figure 6. Along this transition path, the role of renewable hydrogen will also become increasingly important.

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[28] EU Revised Renewable Energy Directive, https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii

3.1.3 Traffic safety

It is a target of the European Road Safety action program[29] to reach "zero fatalities" in Europe by 2050 (See Figure 7).
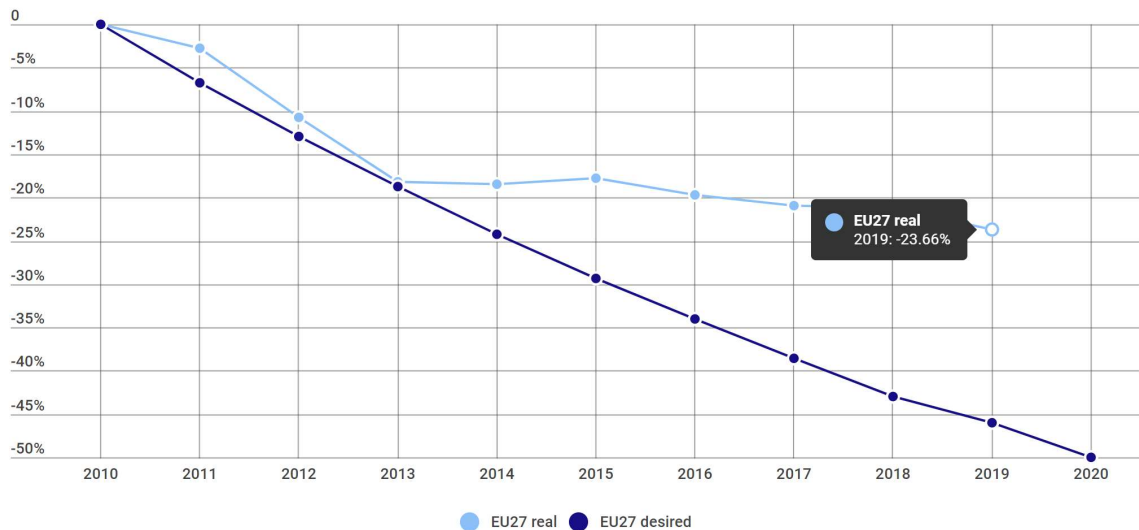
Figure 7: EC ambition for the decrease in the number of traffic fatalities towards 2020.[30]

In 2019, an estimated 22 800 road traffic fatalities were recorded in the 27 Member States[31] of the European Union. This represents almost 7 000 fewer fatalities compared with 2010, a decrease of 23% (The EU target for 2010-2020 is 50% fewer deaths). Compared with 2018, the number dropped by 2%.

Netherlands: 34 road deaths per million inhabitants estimated for 2019, which is one of lowest rates in the EU. Road fatalities fell by 2,5% in 2019 (See Figure 9) .

Still, with 34 road deaths per million inhabitants, every 14 hours 1 person is killed in a traffic accident.
(Status 2019: See Figure 8).
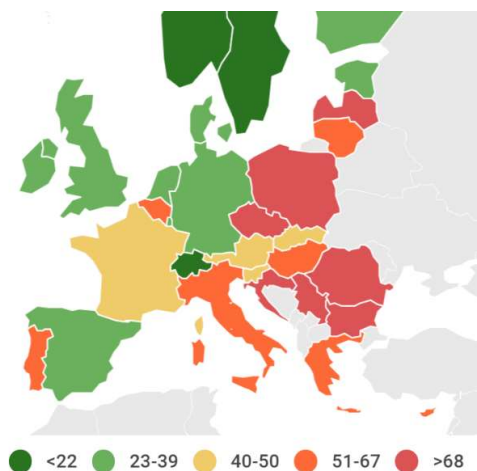
Figure 8. Road deaths 2019 per million inhabitants[32]

As Europe in general, also in the Netherlands, we have seen a significant decrease of traffic fatalities during the last decades. However, this trend was stabilizing to currently almost 13 deaths per week. The rate of severe injuries was decreasing in the same trend as the fatality rate, but in recent years we are faced with a disruptive increase in the Netherlands, mainly among cyclists. The total estimated economic and societal cost of road accident casualties is estimated at 12.5 billion Euros per year for the Netherlands. In overall, a relative change of -2,5% in road deaths was achieved in The Netherlands.

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[29] https://ec.europa.eu/transport/road_safety/home_en

[30] https://etsc.eu/euroadsafetydata

[31] https://ec.europa.eu/commission/presscorner/detail/en/QANDA_20_1004

[32] https://etsc.eu/euroadsafetydata/
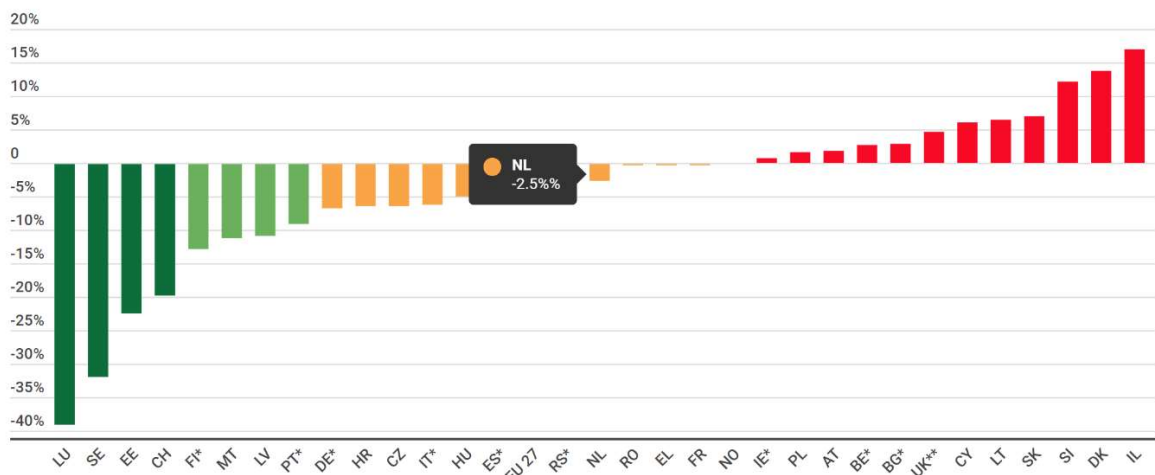
Figure 9. Reduction per Country 2018-2019 [33]

Vulnerable road-users account for 70% of road deaths in urban areas. Overall, car occupants (drivers and passengers) account for 45% of all road deaths while users of two-wheelers make up 26% and pedestrians 21% of total fatalities.

The introduction of more and more smart mobility solutions with "Obstacle Detection functionalities" contributes to decrease the number of incidents on the roads, resulting in declining numbers for fatalities and (severe) injuries. Furthermore, smart mobility solutions should have a clear beneficial effect on the accessibility of cities, the inclusiveness of the mobility system and smooth and strengthened logistics chains.

3.1.4 Accessible, inclusive mobility and accessible cities and regions

Accessible, inclusive and affordable mobility for all will become a huge challenge in the coming decades. The future will be urban: according to the United Nations, 51 % of the world's total population of 6.8 billion people in 2010 was living in urban areas. [Arthur D. Little 2013] expects almost a tripling of kilometres made in urban areas in 2040. Furthermore, globalization is entering a new phase of more connectivity and upscaling in our world. As a consequence, we will see continued growth in the volume and the kilometres made for freight traffic as well as passenger mobility. In its Transport Outlook 2019 [International Transport Forum 2019], the International Transport Forum presented scenarios indicating a global growth in passenger- kilometres from 44 trillion in 2015 up to 122 trillion in 2050.

Road transport supports the activities of people in urban regions and enables transport of goods. However, transport is not without negative consequences. Urban areas suffer from the negative externalities of road transport like congested road networks, air pollution and accidents. The costs of congestion can be substantial. For example, the estimated direct costs of congestion and delays in 2015 in the Netherlands are about 2.3 billion Euros [KiM 2016]. In Europe congestion costs are close to 100 billion Euros per year [EPOMM 2015].

Last but not least, access to mobility will change. Generations that grow up with IT will see less need to be physically mobile or to be owner of transport means. They will become clients of mobility service providers that can accommodate (instant) mobility needs. The vehicle purchase market can ultimately become a market for these providers and require smart connected mobility solutions to provide these services. More and more services will include shared mobility solutions, as well as tailored solutions (including e.g. Mobility

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[33] https://etsc.eu/euroadsafetydata/

as a Service – MaaS). It is estimated that shared mobility solutions, when widely applied and used in urban areas, could halve the number of vehicle-kilometres travelled in urban regions.

Multimodal trips will become more and more normal, and several initiatives intend to combine passenger transportation with the transport of goods.

Taking into account the above societal challenges, it is clear that there is a need to exploit for mobility solutions to mitigate the effects of emissions, to reduce the use of (fossil) fuels and to start the transition towards sustainable fuels. This and the still growing need for accessible, affordable and safe mobility require a well thought automotive roadmap for new smart and green transport solutions.

3.1.5   Urbanization

The dynamics of economically strong urban areas are leading to significant growth, increasing scarcity of public space, and more congestion and emissions. In such situations, an increase in the efficiency of the overall transport system is of key strategic importance, as the potential for major new transport infrastructure implementation is limited by both cost and the urban fabric itself. Efficiency can be achieved through a better provision of different forms of mobility as an integrated service, emission-free drive trains and by making public and shared transport the backbone of the urban transport network. Large-scale implementation and integration of these different aspects is required to address the problems effectively and generate significant relief effects. The priority allocated to public transport must increase with the size and density of cities, especially through dedicated infrastructure for public transport in major cities, such as Bus Rapid Transport, Light Rail, automated metro, regional and suburban services and their combination. In many urban regions, this also is leading to the need for transport hubs. In these hubs, several modalities come together and users (people and goods) can switch modality. These hubs are often located at the entrance of a city, or near an economic top location. There still are many uncertainties in the planning of these hubs.

Almost three quarters of Europe's population lives in cities, towns and suburbs. Recent decades have experienced a trend back to the inner cities – re-urbanization – at least to the vibrant inner cities. At the same time, most cities have been experiencing urban sprawl with housing, jobs and commercial activities located in increasingly dispersed suburbs. Marketing strategies of city governments have been keen to improve the image of agglomerations and thereby further reinforce the qualitative attractiveness of urban areas. Re-urbanization has led to increasing pressure on land and capacity constraints for transport services, particularly in city centres. Further conflicts and competition between transport modes (incl. for parking) and land use (transport versus other functions) can be expected.

Many mobility solutions have been developed to address growing demand, but there is a lack of solutions for areas where overall travel demand is stagnating or decreasing such as in less densely populated or peri-urban areas. Traditional public transport is rarely economically sustainable in these areas. The potential for the deployment of automated shared driving is linked to urban density since such a service will be more sustainable in cities. However, the limit for implementing automated shared transport systems in terms of population density and land use patterns is unknown. Nonetheless, new mobility services and shared mobility can provide new ways of addressing demand in less densely populated areas or in regions where demand is shrinking [ERTRAC 2017b].

Increase energy effiency

- Improve efficiency of whole urban logistics system, energy efficiency of vehicles, decarbonisation

VANS IN LONDON: LOAD FACTOR ONLY
38%

Improve urban environment

- Increase air quality and reduce noise

25% TRANSPORT-RELATED CO_2 DUE TO URBAN FREIGHT

30-50% TRANSPORT-RELATED PM AND NOx DUE TO URBAN FREIGHT
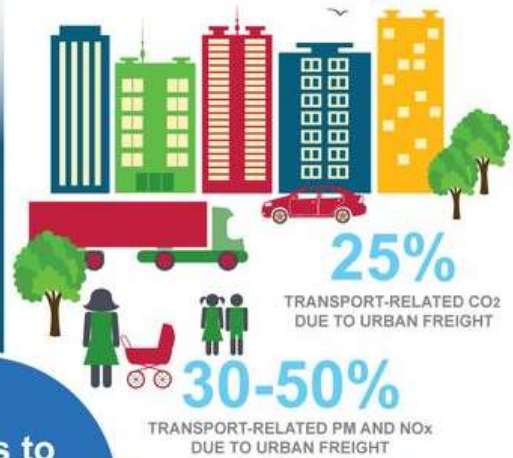
4 ways to improve city logistics

95% B2B DELIVERIES EFFECTIVE (ON TIME, CORRECT PLACE, RECEIVED BY A PERSON)

B2C DELIVERIES EFFECTIVE (ON TIME, CORRECT PLACE, RECEIVED BY A PERSON) **70-75%**

Increase customer satisfaction and reliability

- Deliver goods on time at the anticipated place

53% LONDON CYCLING FATALITIES INVOLVING HEAVY GOODS VEHICLES (2008-2012)

Increase safety and security

- Reduce injuries and fatalities (especially with vulnerable road users) as well as cargo loss or damage

Figure 10: Overview of societal challenges linked to urban environment [ERTRAC 2017b].

4. Technological Multi Domain Trends

This chapter contains the Technological cross-sectoral trends within the Domain of the Automotive Sector. The following sections will address the trends based upon their aspects.

4.1 Digitization and connectivity

In the past few decades, a massive shift towards electronics and controls has entered the vehicle domain. The automotive ecosystem continue to undergo big changes due to the ICT capabilities entering the transport sector [KPMG 2016, KPMG 2017, Roland Berger 2016]. Automotive executives [KPMG 2016, KPMG 2017] rank ICT as key trend disrupting the auto industry in a survey requesting for most important trends affecting the industry until 2030. Ranked #10 in the KPMG 2015 survey, connectivity and digitalisation has moved up to #1 in the KPMG 2016 survey and #2 in the KPMG2017 survey. Related trends include the #7 on creating value out of big data (new since 2016), and #8 MaaS and car sharing. The Battery Electric Vehicle (BEV) is now ranked #1.

ICT and software are one of the key technologies in the vehicle of the future and integration into more complex systems is evolving. The car has become an integrated part of a traffic management system. This technology offers not only new solutions and applications for in car control systems, but also for vehicle to vehicle (V2V) and vehicle to infrastructure (I2V and V2I) communication. Therefore, developments in the automotive industry depend to an increasing extent on cooperation/ input from governments (traffic management), industry and ICT-industry. Sectoral integration, which means the integration of the power sector with the transport and the heating and cooling sectors, is booming; energy carriers such as electricity and hydrogen are needed to achieve European climate and energy goals.
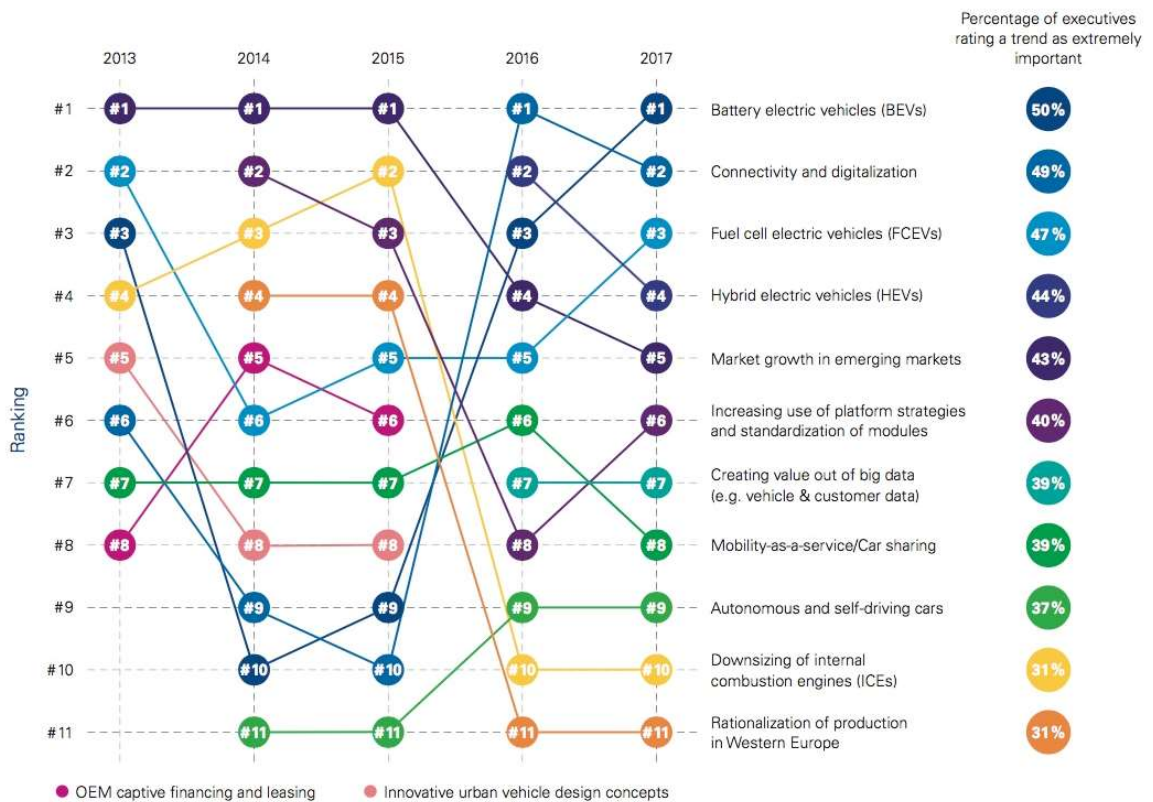
Figure 11: Key automotive industry trends until 2025 [KPMG 2017]

4.2   Smart grids

Smart grids (See Figure 12) typically refer to concepts in which the electric vehicle (EV) is integrated into the electric grid. These concepts enable the further adoption of electric vehicles by increasing charging options, availability and reduction of operational costs. Smart grid applications include smart charging strategies to control the (local) grid load or buffering energy in the vehicle's batteries, e.g. as part of house hold (V2G). Further advances will include optimization of battery life and energy costs. New services bases on planning functions using trip and usage information in combination with charging opportunities are expected to emerge. This is supported by advanced communication, control and metering technology. As shown by Toyota's concept for passenger cars, small, integrated H_2 grid solutions on house hold level are also of interest.
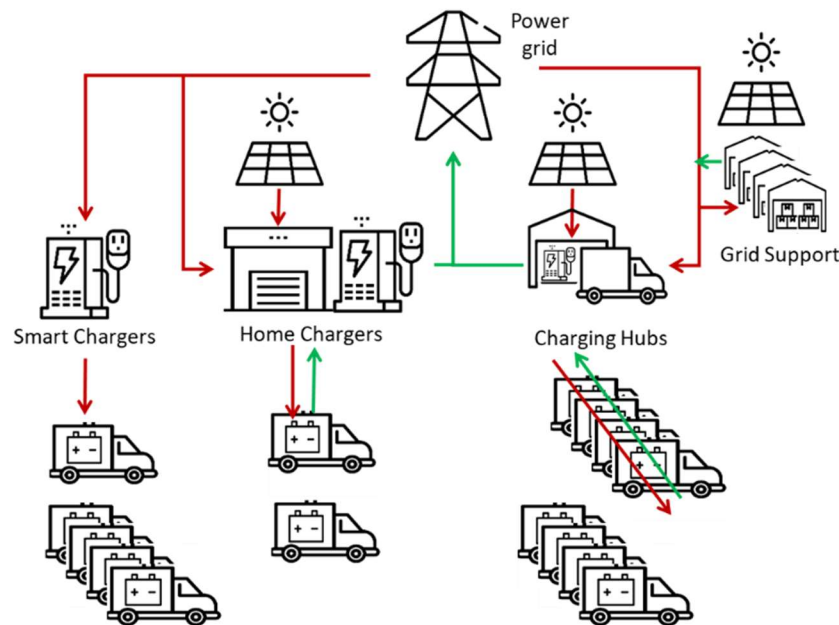
Figure 12. Schematic example of Smart Electrical Grid

4.3   Automation and digitalization

Connectivity has entered the mobility arena with key technology enablers such as (wireless) broadband, positioning, mobile platforms, and cloud computing. Internet of Things (IoT) enables persons, machines and sensors to be connected. The new EU data protection act will enable horizontal data applications and stimulate the sharing economy enabled by the key technology enablers. The vehicle itself will be a big computation platform, with more and more ADAS functions moving to highly automated vehicles, connected to the cloud.

Accessing information about the car and its environment via connectivity solutions shows to be an enabling technology. This technology is well on its way. The main issues that need to be addressed are the security, stability and speed of the connection, however quality assurance and trustworthiness of the data need to be addressed too. These are very important factors as they involve both safety and privacy.

New expectations related to transport of people and goods are emerging. The concept of "transportation" based on a modal approach is evolving into the wider concept of mobility based on a service approach, i.e. the management of Mobility as a Service (MaaS, or Transport as a Service, TaaS, for the transport of goods). The key concept behind MaaS is to put the users, both travellers and goods, at the core of transport services, offering them tailor made mobility solutions MaaS and TaaS provide tailor made solutions, including public

transport, car-sharing, rental car service, taxi and bike or scooter sharing schemes as well as packet logistic services in an integrated way.

The automotive ecosystem will probably change towards at least five new archetypes in which service providers will compete more and more with device manufacturers of controlling the value chain. The five archetypes are:

1) mobility service providers,
2) device manufacturers,
3) infrastructure providers,
4) component manufacturers, and
5) infrastructure component manufacturers.

The first two archetypes are affecting most mobility and vehicle developments. Mobility service providers are at the fat end of the value chain – meaning they are the ones who are in touch with mobility customers of all kind, "the ones to reap the lion's share of revenue and profits" [RolandBerger2016]. Mobility as a Service (MaaS) is an example of a new upcoming concept applied by mobility service providers, with expanding business models. Device Manufacturers are the Vehicle OEMs as we know today. These companies' business model traditionally is limited to developing, manufacturing and selling vehicles. Most of them would sell, or more likely lease, vehicles to mobility service providers as they are the ones with the direct access to the customer with mobility demands.

White Label and Contract Manufacturers deliver commoditized vehicles for different needs and customer groups. The mobility service providers define the vehicle specifications. The focus of innovation would have to shift from product to process and manufacturing technologies[34]. There is also a place for branded OEMs, especially for the ones moving towards the mobility service provider side, like BMW already is experimenting on with their DriveNow mobility concept[35] and Daimler with Car2Go[36]. Customer relationship can be retained by the OEM's, but the centre of gravity will shift towards tech (ICT) companies and mobility service providers [KPMG2016, KPMG2017]. However, to meet these challenges, it is clear that for the branded OEMs informational engineering needs to become a core competence [KPMG 2016, KPMG 2017] to prevent they will move to a white label or even contract manufacturer.

Digitalization within the vehicle itself is already a massive trend, demonstrated by the many ADAS functions available on the market mainly in the high-end models, and will become a commodity coming years due to low costs and widely availability of the components. OEMs will rather evolutionary integrate these functions into level-2 automated vehicles (Figure 13 [37]) then revolutionize like Tesla is deploying new functions through over-the-air software updates. However, the next steps towards higher levels of automation need quite some research-based innovation, both on technological and on human factors perspective. Level-3 automation is still a questionable route whether this is possible due to hand-over control back to the driver in case of emergency situations. It might be more realistic to focus on level-4 automation on classified infrastructure. Prior to higher levels of automation, the use of cooperative systems needs to be extended, as well as building a safe and secure ICT architecture to support (or enable) higher levels of automated driving as stated in the Horizon 2020 agenda[38].

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[34] Roland Berger
[35] https://www.drive-now.com/en
[36] https://media.daimler.com/marsMediaSite/en/instance/ko/car2go-on-the-road-to-success.xhtml?oid=9903589
[37] https://saemobilus.sae.org/content/j3016_201806
[38] https://ec.europa.eu/programmes/horizon2020/en
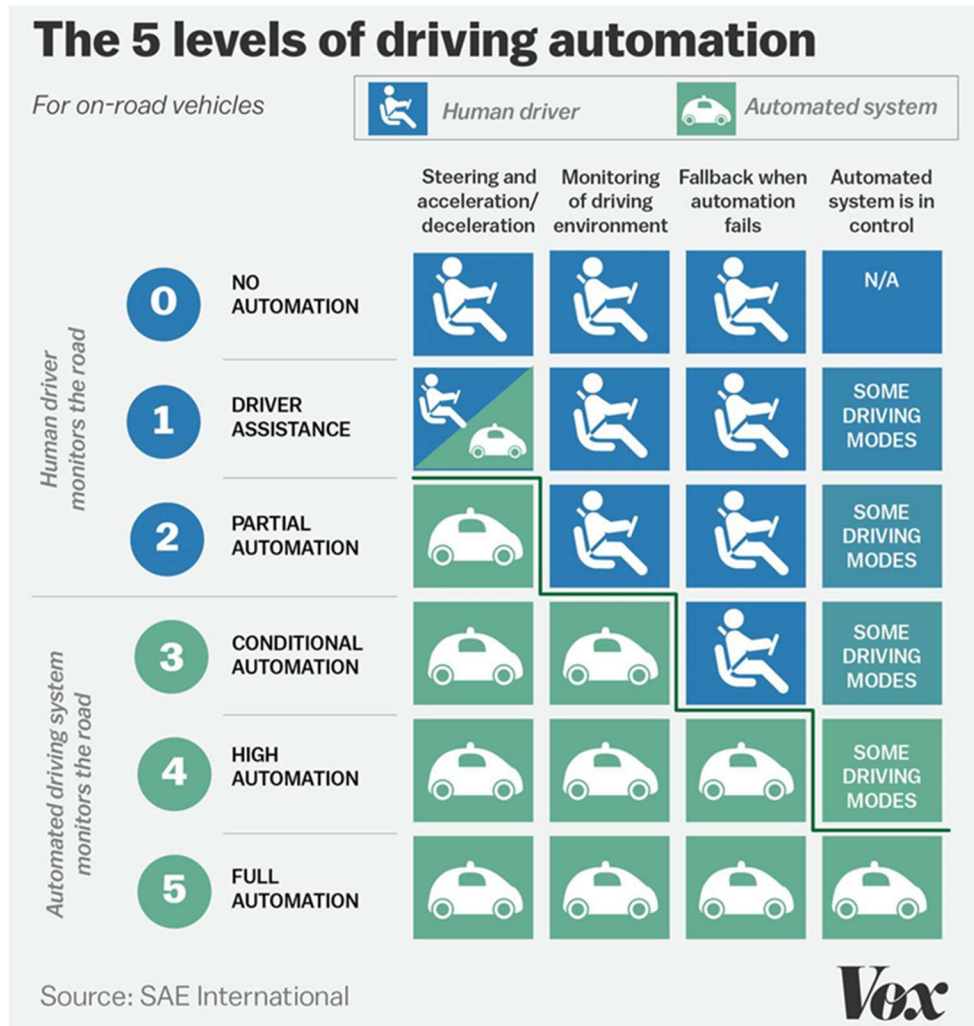
Figure 13. Defined Levels of automated driving for on-road vehicles

With the Declaration of Amsterdam on connected and automated driving[39], European Union Member States, the European Commission and private sector have agreed on joint goals and joint actions to facilitate the introduction of connected and automated driving on Europe's roads. This should prevent a patchwork of rules and regulations arising within the European Union, which would be an obstacle to both manufacturers and road users.

Harmonized legislation and policies in order will enable cross-border mobility with automated and connected vehicles, like truck platoons. This means EU countries must work on compatibility of safety requirements, liability issues, communication systems and services in order to facilitate future market deployment and improve Europe competitiveness in this field. Exchanging views and working together on these subjects will contribute to an integrated approach to automated and connected driving across Europe.

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[39] https://www.government.nl/topics/mobility-public-transport-and-road-safety/question-and-answer/what-is-the-declaration-of-amsterdam-on-selfdriving-and-connected-vehicles.

4.4 Artificial Intelligence (AI)

Artificial Intelligence (AI) has an increasingly important contribution to mobility developments. Due to its powerful performance, AI can contribute to solutions addressing societal and technical challenges like road safety, mobility emissions and congestion, both in cities and on highways. When used in an ecosystem approach, AI can contribute to improved accessibility and inclusivity of mobility services and to sustainability of the transport system.

AI is essential for smart and sustainable mobility technologies and applications:

- On vehicle level, this includes driver support systems, cooperative, connected and automated driving (especially for driver support systems and cooperative, connected and automated driving in complex situations), predictive maintenance, and smart batteries or smart energy usage (based on estimations and fact-based predictions on charging capacities and charging needs);
- On infrastructure level, it includes smart roads, traffic lights and traffic signs.
- Finally, AI will also play a key enabling role in smart mobility service offerings including MaaS.

AI will be the only method able to cope with large volume of data: Automated Vehicles and cross-border application will unavoidably require the development of AI based investigation
The Dutch AI ecosystem is becoming more coherent now, and focused activities in the mobility domain are increasing. [AiNed Strategisch Investeringsprogramma Artificial Intelligence 2021-2027, May 2020] shows the current field of play and investment needs in the Netherlands, including a dedicated section on Mobility. This is detailed further in the position paper "Artificial intelligentie in mobiliteit en transport, March 2020", and reflected with the initiation of the "Working Group Mobility, Transport and Logistics" within the Dutch AI coalition.

4.5 Model-based development

Components and systems (both in the powertrain and in automated driving components) in the automotive domain are becoming increasingly complex. With traditional methods, we have reached a turning point; it is no longer straightforward to optimize overall system performance and guarantee robust performance for a wide range of real-world operating conditions. Also, these methods lead to unacceptable development times and costs. Model-based methods offer the potential to systematically study overall system performance and reduce the number of expensive tests.

A systematic, seamless integrated tool chain that combines advanced testing with efficient model fit methods is currently lacking. The challenge is to find an optimal trade-off between model accuracy and speed (real-time). Another challenge is to integrate multi-domain models and implement fast models on Electronic Control Unit (also Engine Control Unit (ECU)). New, model-based development methods and tools are needed to design, optimize and assess performance of the vehicle and its monitoring, diagnostics and control system.

At the next page, Table 1 illustrates the possible combinations for virtual and real testing (so called mixed testing).

Table 1: Various integration levels of virtual simulation in mixed testing (based on [40])

System level	Software-/ Model-in-the-loop (SIL, MIL)	Component-in-the-loop (HIL)	Powertrain in-the-loop (HIL)	Vehicle-in-the-loop (VIL)	On-road
Traffic	Model	Model	Model	Model	Real
Vehicle	Model	Model	Model	Real	Real
Powertrain	Model	Model	Real	Real	Real
Component* or Sub-System	Model	Real	Real	Real	Real
Ambient conditions	Model	Real	Real	Real	Real

* meaning engine, fuel cell, battery, etc.

List of topics to cover:

- **Mixed testing:** as the system (sensors, vehicles, connected components at intersection) becomes increasingly more complex, an extended (development) testing approach is needed. A clear example can be found in those modelling simulations that can reduce the need of long physical testing sessions. In the automated driving environment this virtual testing are performed by so called Hardware In the Loop systems, where model-based algorithm, opportunely validated via experimental results, can predict the behaviour of a vehicle in specific use cases.
- **Model based development for sub-system (single component):** ADAS/low level controllers-sensor fusion+target tracking (partially)-safety assessment are typically model-based. To reach higher level of automation, the vehicle need to be able to drive under all conditions, making learning from data essential. At the same time, application will be based on existing knowledge on model-based approaches: these are quite mature and more explainable. Therefore, the new trend for these components is to develop an hybrid approach where model-based world will get improvements (being feed and consolidated) by AI world
- **Prediction:** This field of investigation can be split into two main areas: "Prediction at vehicle level" and "Prediction at traffic level". For the "Prediction at vehicle level" it is worth to distinguish:
  - Short term horizon; in which model-based prediction models has good perfromace (generally up to 0.5-0.8s)
  - Mid/long term horizon; where machine learning/AI approaches can model with higher accuracy the trajectory and intention of manoeuvre within 3-4s horizons.
  - Long-term horizon; the interaction between road users also has to be modelled via AI algorithm.
  For the "Prediciton at traffic level":
  - Model-based approach will be the first methods to be applied (as for instance on traffic density or for the analysis of automated vehicled in mixed traffic conditions), considering information from the cloud and from the "crowd" (as , for insatnce the information gathered by smartphone apps).

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[40] F. Willems. P. van Gompel, X. Seykens & S. Wilkins, 2018, Robust real-world emissions by integrated ADF and powertrain control development, Book Chapter, Control strategies for advanced driver assistance systems and autonomous driving functions : development, testing and verification. Waschl, H., Kolmanovsky, I. & Willems, F. (eds.). Springer, p. 29-45

4.6   Cyber security

Systems for CCAM enabled mobility must be fail-operational and cyber-secure in their entire Operational Design Domains (ODD). This should guarantee a safe and secure operation of vehicles independent of the respective security level the element (component, vehicle, infrastructure or communication part) has in its respective Operational Domain.

Cyber security issues are arising together with the rise of connectivity and with the active use of Internet of Things (IoT). The cyber security risks are related to connectivity issues, data breach, malicious actions as well as system failures. As the consequences can be on vehicle level but also on the transport system level, this needs to be taken care of in an early stage. Besides the automotive industry, actors from the telecom industry are needed to develop viable solutions in a joint approach; cyber security needs to be tackled both at component level and at integration level where components are brought together.

According to the Global Cybersecurity Index (GCI)[41], within Europe The Netherlands held position nr.5 in 2017 and dropped to nr 8 in 2018. Although version 2020 is not released yet, the indication is that cyber security demands a higher level of attention.

4.7   Physical and digital infrastructure

Road Infrastructure will play a substantial role for the realization of Cooperative Automated Mobility in the coming years, in both complex urban- as well as in rural- environments. The trends of road infrastructure will be mainly towards two direction:

1) Create a digital twin of physical infrastructure supporting the autopilot of the vehicles,

2) Enabling the interaction of traffic management with CAV in situation falling outside the ODD of the vehicles (e.g.: request for an emergency lane change due to traffic accident).

Moreover, the target of SAE level 4 of Automated Vehicles (as shown earlier in Figure 13) will require a higher levels of Infrastructure Support for Automated Driving (ISAD), identifying the infrastructure adjustment and improvements -both Physical and Digital- necessary to match the need of cooperative mobility.

4.8   Demographic trends

Ageing is one of the greatest social and economic challenges of the 21st century for European society that will affect most policy areas. By 2025, more than 20% of Europeans will be 65 or older, with a particularly rapid increase in numbers of over 80. Older people are most likely to experience mobility difficulties. A reduction in mobility can impact the quality of life and psychological well-being at an older age. The ageing of society therefore also brings new demands for mobility and accessibility in urban areas, especially in areas that are perceived as critical to safety.

4.9   Trends related to human capital

The changes enforced by the societal market, as well as technological trends require the education institutions to respond. The speed of innovation at companies is different than how necessary changes within the educational system can be implemented. Relevant trends in 'mobility issues' lead to a shift towards other cross-disciplinary fields such as traffic management and disciplines like psychology and user centred design for the design and engineering of in-car systems.

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[41] https://www.itu.int/dms_pub/itu-d/opb/str/D-STR-GCI.01-2018-PDF-E.pdf

On a global scale research is necessary in the fields of combustion processes, materials, electro-mechanics and power electronics, hybrid powertrains, new battery systems, testing, mechatronics and control, vehicle dynamics, systems research, car2car communication, model driven software engineering, verification of software, traffic modelling and flow control. Moreover, the involved scientific research teams are well embedded within the high-tech systems research areas and benefit from the mutual questions at system level (i.e. mechatronics, systems and control, ICT and embedded systems).

On the EU level, the integration of the power sector, the transport sector and the heating and cooling sectors via the use of all energy carriers such as electricity and hydrogen is becoming more important to achieve European climate and energy goals; the so-called "Sectoral integration".

The engineer of the future will need skills and capabilities that are perhaps not taught at schools today. Especially with the Smart Mobility area there will be an increasing focus on monitoring and aiding the driver in driver tasks in order to develop an adoption of the fully automated vehicle later on.

The traditional focus has predominantly been on vehicle design and production. This will need to change in order to educate future engineers who will be capable of tackling the relevant technological challenges and realizing the innovations that have been set out in this roadmap by the Dutch automotive sector. New technologies require new teaching skills, and new educational concepts (i.e. online) that will allow for a flexible adoption of new technologies within the scope of the curriculum. System thinking, new smart mobility solutions, manufacturing challenges of automotive OEMS and suppliers are some of the major trends as well as drivers of changes related to the Engineer of the Future. Parts of this have been implemented already within the new Automotive bachelor, master and PDeng at the TU/e, as well as within the Automotive Centre of Expertise (ACE). The Automotive sector is often used as an example where the relation between trends in the sector and the changes within the educational system are well interlinked, and also the relation between all levels of education is often referred to as an example.

The goals of the relevant human capital activities are related to four major aspects:

3. **Quantity**: More students, more engineers of the future.
4. **Quality**: Students are educated for the future needs of the industry
   - Smaller gap between educational organizations and industry
   - Inspiring teachers with up-to-date knowledge inspire and educate the Engineers of the Future
5. **Research:** Joint participation and involvement of students, teachers, researchers, and companies in projects is necessary in order to keep the knowledge level of all stakeholders up-to-date
6. **Career talent development**: Employability to a future sustainable workforce

4.10   Sustainable Manufacturing[42]

The business climate for the Dutch Automotive Industry has developed over the past decades from regional to European and even global. The current playing field is an international industry where companies must deal with international competitors, customers and suppliers and their challenges. In order to be able to produce in high volumes at competitive prices, the relocation of production installations to cheap countries requires noticeable or a high degree of automation. Another issue today, which will remain in the future, is fluctuating demand from a more diverse customer base. This forces companies to include a higher level of flexibility in their manufacturing process. In addition manufacturing companies are faced to reduce CO^2 emissions and introduce circularity, driving a growing awareness of strategical adaptations to remain competitive.

Future prospects and the development of high-quality, sustainable, circular and intelligent production are the general trend, in addition, depending on the development of various mobility concepts, we may see trends such as; maximum production flexibility and low cost high volume production lines. Whilst adding value is and remains an absolute necessity to make sufficient margin.

Corona teaches us that it is reasonable to assume that reliance on supply chains outside the EU can be risky and EU chains may offer more stability. Products will also imply a strategy for future disassemble, refurbish and recycle as part of a product life cycle.

4.11   Circularity

Both societal challenges and regulations bring challenges for the production industry to improve energy efficiency. Sustainability in the production industry implies energy-resource efficiency with a minimal impact on the environment and society. In this process of continuous improvement, emphasis has been placed on the reduction of carbon dioxide emissions. By revising production processes and technologies, manufacturers can respond to this development of sustainability trends and still remain competitive. As a general term, 'eco-design' is often used to cover the sustainable design of activities that could also be applied in the production sector. In order to standardize such a development, the International Organization for Standardization (ISO) created a Project Committee (PC242 - energy management). This committee developed a management system standard[43] providing an international framework for industrial factories or companies to manage energy, including all aspects of procurement and use. This is equal to companies that have (i) a sustainable management system, (ii) conduct research upon basic energy use and (iii) are committed to continuously improving their energy performance. In the short term, this 'eco-factory model' should strive for (a) the optimal utilization of energy flows, (b) the reduction of environmental impact such as landfill and (c) the improvement of resource efficiency in order to achieve long term goals.

The above mentioned trends will put an Industrial focus upon the following three aspects;
1) Environmentally friendly,
2) Economic growth,
3) Social well-being.

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[42] https://www.raivereniging.nl/artikel/nieuwsberichten/2020-q2/0406-focus-document-and-action-plan-automotive-manufacturing.html
[43] ISO 50001:2018

5. Technological Applications

This chapter summarizes the main observed technological developments, which contribute to meet the identified societal challenges on vehicle level. In support of the realization of integrated and sustainable mobility, this is done for two focus areas:

- **Sustainable Mobility and Transport** – zero emission vehicles that promote the transition towards renewable energy carriers;

- **Smart Mobility and Transport** including advanced driver assistance systems (ADAS), connectivity and automation.

Efficient, Sustainable & Flexible Factories is not included here, as it already is addressed in the HTSM Smart Industry Roadmap, whereas the development of (new) high tech materials, is addressed in the High Tech Materials Roadmap.

5.1 Sustainable mobility and transport

In the upcoming decades, the automotive industry faces enormous challenges to dramatically reduce CO_2 emissions from vehicles. If human behaviour and vehicle technology remains unchanged, global greenhouse gas emission are expected to double in 2050[44]. There is not a single solution to realize the required massive reduction levels; besides change in human behaviour, a combination of logistical, traffic and vehicle measures with sustainable fuels and energy carriers is needed, see also Figure 14. This clearly illustrates the complex interaction between the different domains and the need for an integrated systems approach[45]. The identified domains are in line with international roadmaps and with the National Multi-year Mission-oriented Innovation Plan (MMIP[46]) nr. 9, 10 and recently 13.
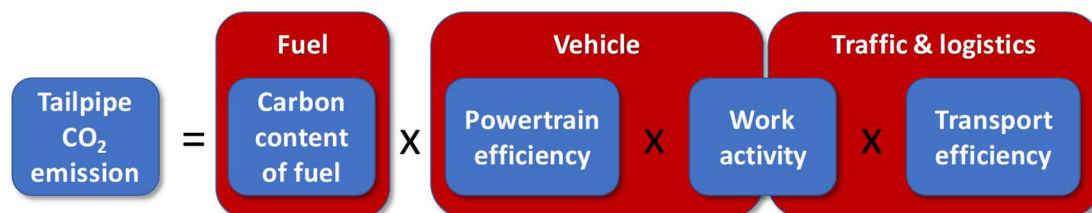
Figure 14: Illustration of relevant domains for GHG emission reduction in freight transport

On vehicle level, various technological trends are observed, which contribute to future climate-neutral mobility. On short term, a shift towards electric vehicles is foreseen for passenger cars and city distribution applications. Heavy-duty truck applications focus more on electrification and energy efficiency optimization of the internal combustion engine (ICE)-powered solutions and on transport efficiency maximization by increasing truck capacity using eco-combi's (e.g. from 40 ton to 60 ton with High Capacity Vehicles). The vast majority of the electrified platforms will include plug-in capability. In the long term, technological solutions are expected to converge for the different light- and heavy-duty applications to solutions that support the use of electricity, hydrogen and sustainable fuels (or E-fuels), in combination with more widely

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[44] UN Intergovernmental Panel on Climate Change (IPCC) - https://www.ipcc.ch/report/ar5/wg3/
[45] https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2018/06/26/position-paper-co2-standardisation-for-heavy-duty-vehicles/position-paper-co2-standardisation-for-heavy-duty-vehicles.pdf
[46] https://www.topsectorenergie.nl/missies-voor-energietransitie-en-duurzaamheid/mmip

accessible refuelling infrastructure. In addition, connectivity, automation and AI will be at the core of fundamental changes in mobility. Also, multi-modal transport is of interest, but this is out of scope here.

The trends are discussed from a technological point of view. A wide range of applications in light-duty as well as heavy-duty automotive applications is foreseen, and where possible maximising the sharing of modular components, standardisation, and charging/refuelling infrastructure between platforms. However, the identified powertrain technology developments are also strongly linked to non-road applications. The anticipated powertrain solutions are also of interest for marine, non-road mobile machinery and stationary energy production applications.

For the theme Sustainable Mobility and Transport, the technological trends are clustered around three subthemes:
1. Maximize vehicle efficiency;
2. Powertrain concepts for sustainable energy carriers;
3. Smart energy management.

Their contribution and impact is discussed in more detail in the following sections.

5.1.1   Maximize vehicle efficiency

Due to technology maturity and cost effectiveness, much attention has already been paid to maximize vehicle efficiency. Three focus areas are distinguished: i) maximize energy conversion efficiency of the powertrain and ii) minimize the required vehicle power demand and iii) maximize the mobility/transport efficiency.

5.1.1.1   Maximize powertrain efficiency

To maximize powertrain efficiency, developments focus on increasing engine and drivetrain efficiency. Europe is the cradle of the internal combustion engine (ICE), and must leverage its know-how to develop this technology further. For existing ICE-based concepts, there are still opportunities for efficiency improvement and emissions reduction by the adoption of electrification, advanced exhaust gas aftertreatment and optimization of the combustion process and of drivetrains.

The importance of hybridization is expected to grow even further, not only to increase efficiency by energy recuperation and engine load optimization, but also to enable zero emission driving in cities for heavy-duty applications. In addition, increased attention is paid to energy recovery systems (including electrically-assisted turbo charging, turbo compounding and waste heat recovery) and avoiding losses, e.g. by power-on-demand using electrification of auxiliaries. Also, highly efficient, advanced combustion concepts are examined. It is noted that this is not only limited to heavy-duty applications.

5.1.1.2   Minimize vehicle power demand

All concepts benefit from minimizing the vehicle power demand. Besides reducing vehicle mass, reduction of air and rolling resistance are important research areas. As a result, demonstration programs on the potential of low rolling resistance tires and tire pressure monitoring systems are ongoing. For long haul heavy transport, aerodynamic measures, such as wheel covers, skirts, and trailer tail, are of particular interest. For the midterm, advanced vehicle concepts, including active flow surfaces and reconfigurable truck-trailer shapes, are examined. Also, truck platooning enables air drag reduction, but the actual impact depends on inter-vehicle distance and location in the platoon.

Another important research area for minimizing the requested vehicle propulsion power is the optimization of vehicle speed profiles. More precisely, minimizing energy losses related to vehicle acceleration as well as recovering energy during deceleration for re-use. In this area, attention is moving from driver training, via driver-assist systems towards automated driving. The role of advanced eco-driving, connectivity and automation is discussed in more detail in the Sections 5.1.3 and 6.1.4.

5.1.1.3   Maximise the Mobility/Transport Efficiency

In terms of kWh per passenger-km or tonne-km, several measures (often combined with improved logistics, such as concepts around shared platforms to maximize vehicle utilization, different regulations on vehicle speed/automation, as well as physical internet planning on operation), can arise at lower GHG emissions. These include aspects of maximizing the passengers or cargo per vehicle, often through improved vehicle design, longer/heavier vehicles, improvements in terms of light-weighting where GVW is a limiting factor.

5.1.2   Powertrain concepts for renewable energy carriers

Vehicle efficiency reduction measures mainly focus on meeting short-term GHG reduction targets and are only a first step in the transition towards sustainability mobility. In this transition, an increased focus on powertrain concepts that enable the use of renewable energy carriers is observed. Currently, there is general consensus that there is not one single pathway to climate neutral mobility. To meet future decarbonization targets at lowest possible cost, all energy carriers that can contribute will be needed. Although various energy carriers (incl. ammonia and metals) are studied, for sustainable powertrain and vehicle concepts, three climate neutral energy carrier pathways (in the sense of zero well-to-wheel GHG emissions) are considered to be most promising (as illustrated in Figure 6): renewable electricity, renewable hydrogen and biofuels / E-fuels (or power-to-X).

This section discusses various powertrain concepts that enable these energy transition pathways. The heavy-duty powertrain developments are also relevant for marine, non-road machinery and stationary engine applications.

5.1.2.1   Electrified powertrains

Electrified vehicles, including fully battery electric (BEV) and hybridized vehicles (PHEV, HEV), are likely to be the predominant powertrain configurations of the future. As such the battery and charging in its various forms and sizes will be key consideration in future. However, different vehicle types may be spread over this electrification spectrum, based on the size and nature of the powertrain configuration.

For passenger cars, a clear shift towards battery electric vehicles (BEV) is picking up. This is illustrated by the increasing number of BEV models that become available on the market, with increasing range and declining prices. A continued city focus is observed in the transition towards low or zero emission zones which strengthen the pull for technological solutions for highly electrified vehicles. City zoning is expected to come into play by 2030. Up to this point, vehicles prominently used only within cities, such as public transport (buses), medium-duty commercial vehicles and light-duty vehicles, are expected to see significant evolution to highly electrified (if not fully electric) and resulting market uptake. With the introduction of zero emission zones, it is also foreseen that first/last mile zero emission driving for heavy-duty application will be required. Here, powertrain hybridization (series, or P2 and above[47]) is seen to be an important solution and one which inherently has flexibility able to accommodate to a wider range of operational needs and available infrastructure.

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[47] https://x-engineer.org/automotive-engineering/vehicle/hybrid/mild-hybrid-electric-vehicle-mhev-architectures/

Battery technology in particular has been accelerating over recent years, driven by large-scale investment, prominently from the light duty sector. Alongside advances in performance and lifetime, the reduction of cost is perhaps the most promising aspect, fueled not only from technology advances, but also from the upscaling of production volume. That said, significant challenges remain to further improve, not only at the cell, but also at the pack design, integration, charging, thermal management, light weighting, and battery management system (including both electronics and control).

Lithium-ion battery price outlook

Lithium-ion battery pack price (real 2018 $/kWh)

2024 implied price $94/kWh

2030 implied price $62/kWh

▲ Observed prices — — 18% learning rate
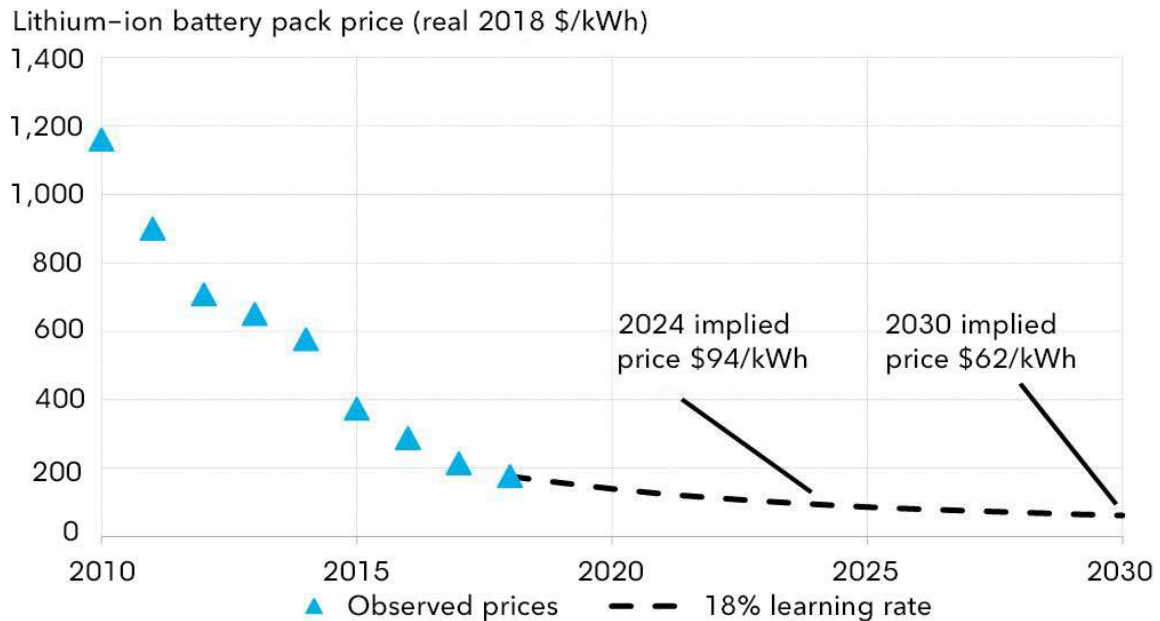
Source: BloombergNEF

Figure 15: Trend and outlook in Lithium Ion battery price [48]

Europe faces the challenge to catch up with other regions in the development and manufacturing of battery- and fuel-cell electric vehicles and the components for these powertrains. Although a large amount of IP sits within Europe, large-scale investments are needed in factory infrastructure. More-recently, this is being addressed in two large initiatives under the IPCEI[49] legal framework to apply member-state structural funds to establish this capability for European Competitiveness. These two large instruments are the Battery Alliance[50], and Clean Hydrogen Alliance[51] with multiple billions of euros earmarked to build up factories and infrastructure. It remains unclear to what degree the Netherlands will participate, and if so within which niches, and this remains and ongoing discussion.

Without such a transition in the European industry the market for electric and fuel cell vehicles will be lost to Asian and US manufacturers. Driven by the need to further reduce battery costs, enhance energy density and life time, developments on next generation batteries (e.g. solid state batteries), battery monitoring systems and energy management are crucial.

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[48] https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/
[49] Important Project of Common European Interest
[50] https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en
[51] https://ec.europa.eu/growth/industry/policy/european-clean-hydrogen-alliance_en

5.1.2.2 E-fuels based ICE powertrains

Production rates of liquid biofuels have been increasing over the years. This results in increasing biofuel mixing ratios in today's fuels at the gas station; in Europe, today's standard gasoline and diesel contain 10% bio content. Modern vehicles can deal with this fuel specification. Also, gasoline and diesel with 85% and 100% bio content are available in relatively small amounts. However, these fuels set specific requirements for usage in today's engines.

To reduce tailpipe CO_2 emissions, some European manufacturers follow the route to introduce powertrains that enable the use of low carbon fuels. Especially, natural gas is a promising option; up to 25% CO_2 reduction compared to Diesel fuel based on energy content. This is also supported by plans to realize LNG terminals in large ports and a LNG infrastructure along the main European transportation routes (TEN-T)[52].
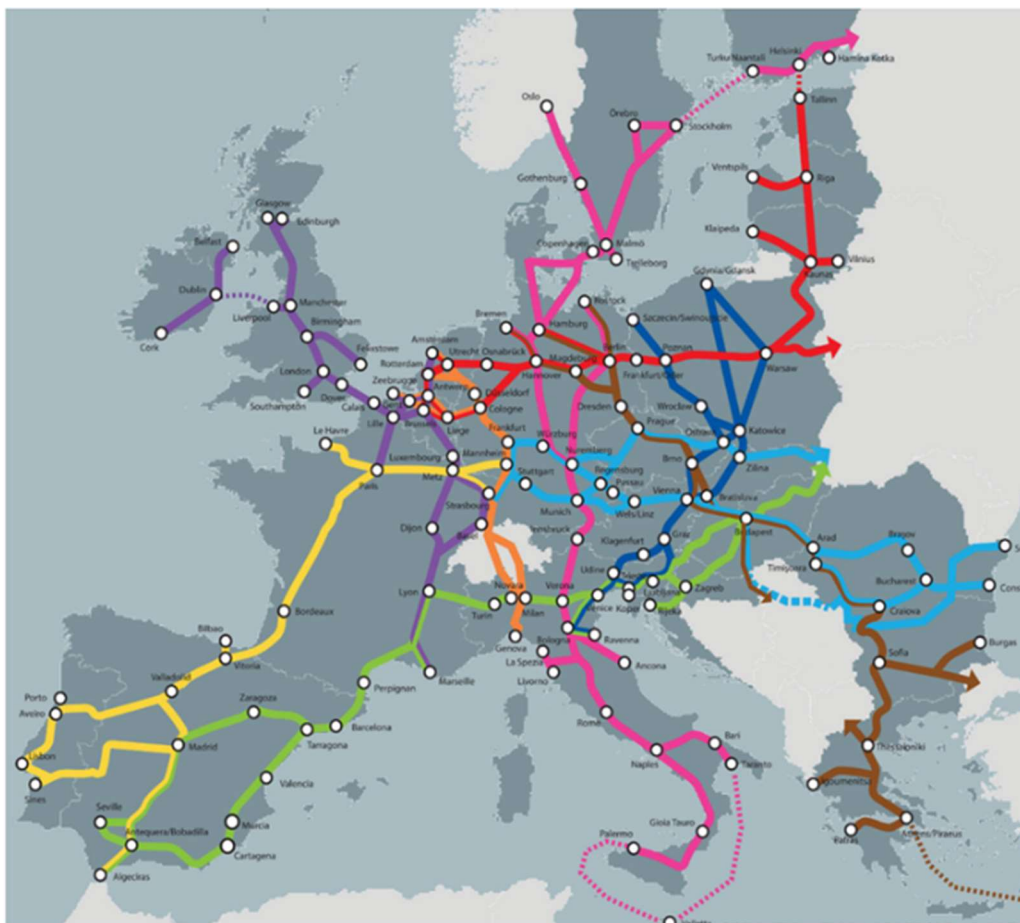
Figure 16. European transportation routes TENT-T

Research and development mainly concentrates on the combustion process: enhancing efficiency and durability by clean stochiometric SI concepts and by new lean burn dual-fuel high pressure direct injection (HPDI) concepts. For these concepts, challenges are related to safe on-board storage of sufficient amounts of fuel and minimizing tailpipe methane (CH_4) emission, which has a significantly higher global warming potential than CO_2. With the production of bio-methane, this route is a transition path, which is also a sustainable for long term solution.

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[52] https://ec.europa.eu/transport/themes/infrastructure/ten-t_en
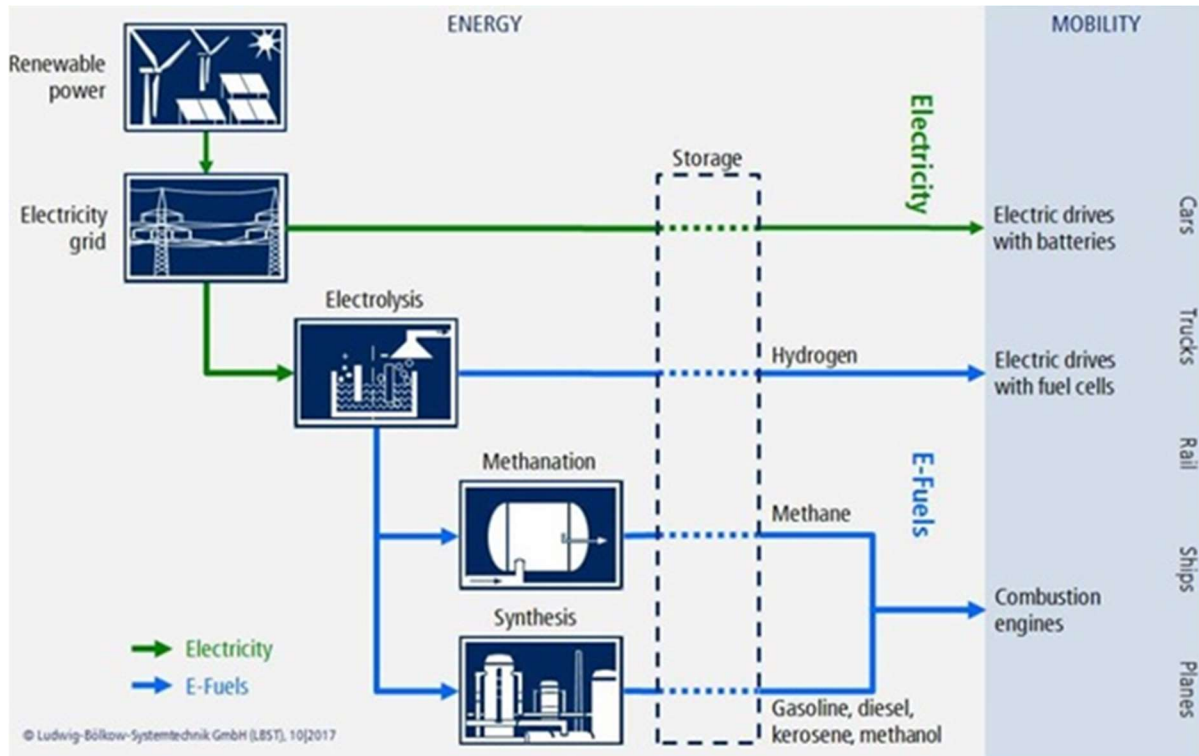
Figure 17. Overview of scenarios for the production of renewable energy carriers for mobility [53]

The internal combustion engine is expected to remain the primary power source of heavy-duty applications in the upcoming decades. For the decarbonization of these applications, renewable fuels are expected to play an important role[54]. This is mainly motivated by energy density, compatibility to existing infrastructures and availability. Carbon-based synthetic fuels will be typically produced from biomass or from CO_2 (captured from process emissions or from air) using surplus of renewable electricity, see (Figure 17). These fuels are often referred to as E-fuels[55] or sun fuels. To supply large amounts of fuel, it is essential to enable the use of renewable fuels from various sources. Aside from production efficiency to enhance cost effectiveness, advanced combustion concepts are under investigation that combine very high engine thermal efficiencies with ultra-low engine out NO_x and soot emissions and that enable the use of a wide range of these fuels. These concepts can either deal with design fuels that are blended in the production process (such as Partially Premixed Combustion) or rely on combination of a range of two fuels (in Reactivity Controlled Compression Ignition).

5.1.2.3   Hydrogen-based powertrains

Besides using renewable electricity and E-fuels, hydrogen (H_2)-based concepts are a third, important pathway towards climate neutral mobility. This pathway raised increasing attention over the last few years due to its corresponding zero tailpipe carbon emissions. In particular for heavy-duty applications, also energy density and corresponding driving range make it an interesting alternative for electric vehicles. However, safe and cost-efficient on-board storage of sufficient amounts of hydrogen is still an important hurdle for all powertrain concepts, as well as wider-spread availability of refuelling stations.

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For light-duty applications, fuel cell electric vehicles have been introduced in the market. Relative to fully electric vehicles, its market share is small. Pilot studies with delivery trucks, longer haul distribution trucks, and rural buses/coaches are ongoing and are expected to see larger scale applications in the near future. For trucks, also research programs are started to demonstrate the technology and study the potential to scale up this technology for heavy-duty applications, including new concepts on mobile infrastructure and localised fuel production.

Besides cost reduction, increased demonstration of fuel cell behaviour in automotive applications will enable the wider understanding of fuel cells by a range of mobility and transport end-users. Additionally, improving modularity, design and integration tools, minimizing the need for precious materials and maximizing durability and energy efficiency is elementary to maximized performance and cost efficiency. Similar to H_2-ICE, the level of required hybridization to improve transient performance and enhance power density is needed for heavy-duty automotive applications, where the fuel cell can be used as a prime-mover or as a range extender.

Until recently, applying hydrogen in internal combustion engines (H_2-ICE) only attracted minor attention. Driven by GHG legislation and introduction of zero emission zones, this is changing. H_2-ICE concepts rely on mature and robust combustion technology, which makes it an interesting cost-efficient solution for the short term. It can deal with varying hydrogen quality as well as mixtures of natural gas and H_2.

The higher combustion temperatures and lower power densities still present challenges to bring this technology on the road, and more insight in thermal engine load and aftertreatment requirements is needed. Also, the level of required hybridization to improve transient performance and enhance power density has to be examined. On the longer term, very high engine efficiencies in combination with ultra-low engine out emissions are foreseen by applying advanced combustion concepts. If low-NOx combustion concepts are used, this technology can also play a role in reducing the current problems related to nitrogen deposition.

5.1.2.4 Recharging and Refuelling Infrastructure

Impact, affordability and availability of renewable energy carriers are crucial in the energy transition towards 2050. In this transition, it is important to avoid technology lock-in; technology paths (and related investments) should not only give a short term perspective, but should also support long term solutions. With respect to impact and affordability, there is a strong link with the research area 'Energy'. The transition towards green electricity, green hydrogen and E-fuels needs time and huge investments. Knowledge on the energy production processes is required to assess their impact on environment (in terms of well-to-wheel GHG emissions) and on energy pricing. Note that this is relevant to assess impact, but it is outside the scope of this roadmap.

Availability of large amounts of renewable energy carriers is key to realize the desired transition. For the three main identified energy transition pathways, the application of bio- and E-fuels is compatible with the existing gas station infrastructure and supports drop-in scenarios. For green electricity and hydrogen, besides the realization of sustainable production processes, the realisation of dedicated distribution infrastructure is crucial for the growth and acceptance of related powertrain technologies. In Europe, the number of fast electric charging stations is rapidly increasing. Furthermore, increasing numbers of small grids of households and companies offer opportunities for electric charging. For higher power electric charging (or localised grids with multiple users), grid-coupled storage appears to be one promising method of stabilising demand/supply. The flexibility of such a mobile charging infrastructure assists with the upscaling and logistical optimisation over time. For hydrogen, currently there are approximately 130 filling stations in Europe, but this network will expand rapidly according to planned investments[56].

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[56] https://h2.live/en

Electric Road Systems (ERS), which are using e.g. a catenary for power supply while driving, may evolve for heavy-duty road transport. However, it remains open whether interoperability can be fully achieved, user acceptance rises and high up-front infrastructure investments can be justified. The move to higher DC voltage levels, increased power fast charging, and ever continuing battery cost reduction and energy density improvements are expected to unlock some business cases over the next few years.

5.1.3 Smart energy management

Control systems are the brain of the powertrain and the vehicle. These systems give the vehicle its specific characteristics in terms of driveability, energy consumption and emissions. With the introduction of more and more subsystems, their importance will grow even further in the future. To exploit the synergy between the engine, drivetrain and energy recovery systems, energy management is key. In this area, there is a trend moving from powertrain to vehicle level; total energy management covering the various vehicle energy buffers and sources, including vehicle thermal systems (cooling systems, cabin) and advanced vehicle concepts based on smart trailer solutions, such as trailers with electrified dollies. Also, strategies are seen that cover the interaction of the vehicle with its environment. By system design optimization and smart control, the synergy between these energy systems and buffers is fully exploited. This will not only minimize operational costs, but will also improve driving range and passenger comfort (e.g. pre-trip heating of cabin).

For the highly electrified powertrains, management of battery packs towards lifetime optimisation, taking into account charge and thermal management strategies is driven from improved modelling, data-mining, novel sensors, and control alongside the hardware innovations. Verification and validation of these needs advances in mixed testing and accelerated testing.

Control systems also have to guarantee that legal emission limits are met under a wide range of operating conditions, but also ensure the desired functionality of the vehicle. This not only sets requirements for control, but also for on-road performance monitoring. With the introduction of zero emission zones, this will even become more challenging for ICE-based hybrid-electric powertrains. Here, an integrated energy-emission management approach is needed.

Driven by developments in the area of connectivity, automation and AI, more information will become available on-board and situation awareness will be significantly improved. This includes future route and traffic information as well as real-time information on component, powertrain and vehicle state. So far, this information is mainly applied for enhanced safety and comfort. A next step is the development of advanced eco-driving and eco-routing functionalities. By using the on-board information for on-line optimization of powertrain and vehicle performance, real-world energy consumption and emissions are minimized, whereas control development time and costs can be dramatically reduced by innovative auto-calibration (or self-learning) concepts. This development will go hand in hand with the introduction of new generations of electronic control units.

5.2 Smart Mobility

The theme Smart Mobility is built on four subthemes:
- Connected Cooperative Driving,
- Automated Driving,
- Connectivity, and
- Smart Mobility Services.

Connected Cooperative Driving means that vehicles are communicating with each other and/or with the roadside, a back-office, etc., while aiming to optimise both the individual driving as well as the traffic flow and traffic safety. Automated Driving means that vehicles are equipped with technologies that enable them to act automatically, independent of a human driver, or supporting the human driver in complex situations. Connectivity means that vehicles exchange information with other vehicles or roadside units; the data sharing then does not necessarily have an overarching aim to improve the situation on a systems level. Smart Mobility Services are enabled by the connectivity and data sharing, and aim to deliver a personalised, tailor made mobility solution to the customer. In many cases, this involves multi-modal solutions. Combinations of transport of people and goods can be seen in this subtheme as well.

Automated Driving is seen as one of the key technologies and major technological advancements influencing and shaping our future mobility. The main drivers for higher levels of Automated Driving are:
- **Safety**: Accident avoidance and mitigate consequences of accidents.
- **Clean & Energy efficient:** Decrease fuel and energy consumption and reduce emissions.

Further important drivers include:
- **Efficiency**: Increase transport system efficiency and reduce time spent in congestion, remove redundant or unnecessary trips.
- **Comfort**: Enable user freedom for other activities while automated systems are active.
- **Social inclusion**: Ensure mobility for all, including elderly and impaired users.
- **Accessibility**: Facilitate access to city centres, facilitate access to mobility and to transport of goods.

The ERTRAC roadmap on Connected and Automated Driving [2019] (A.3.1 - 1)) is very relevant for the Dutch situation. The overall objective is to identify challenges for implementation of higher levels of automated driving functions. A lot of work has been done on this topic by various stakeholders and multi-stakeholder platforms (e.g. EUCAR, CLEPA, EARPA, EC CCAM Platform, ERTICO, EPoSS) and in European research projects like ARCADE. Therefore, it is essential to avoid any duplication of activities and concentrate on the missing items, concerns and topics for future implementation.
For the levels of automation and driver support the definitions of SAE J3016, defining the Levels of Automated Driving, are commonly used (see Figure 13). Their latest version shall be used, after the revision adopted in June 2018, as accessible on: https://saemobilus.sae.org/content/j3016_201806.

The technologies and applications mentioned so far, all have their specific application area (including speed), type of environment (including road type), interactions and aims. This framework of intended use of the technology or function is the so-called Operational Design Domain, ODD. ODD is a description of the specific operating conditions for which
the automated driving system, application or technology is designed to operate. This includes e.g. roadway types, speed range, environmental conditions, prevailing traffic law and regulations. An ODD can be very limited: as an example, there is the case of a single fixed route on low-speed public streets or private grounds (such as an industrial campus) in temperate weather conditions during daylight hours. It is up to the manufacturers of the system to specify the ODD for their automated driving system, but a coordinated approach is the most promising.

Typical ODD differentiation is based on different types of roads. Some roads and areas are more suitable to first introduce systems involving increasing levels of automation, before the systems can be deployed to open roads. The most commonly used descriptions are given here:

- Confined areas with restricted access control, such as terminal areas and ports.
- Dedicated road/lane where vehicles with specific automation level(s) are allowed but the area is not confined, such as parking areas and dedicated lanes.
- Open road with mixed traffic in single or multiple lane operation on local, regional, and
- highway operation, for use by vehicles with any automation level. Regulation (local, regional, national, European) needs to be taken into consideration.

There are three categories of vehicles relevant for the Automotive Roadmap when it comes to connected and automated mobility:

1. **Automated Freight Vehicles:** This path focuses on automation of commercial vehicles primarily for long-distance freight transport. Automated commercial vehicles operate mainly on open roads but also in restricted roads/lanes and confined areas.
2. **Automated Passenger Vehicles:** This path focuses on automation of private/shared vehicles both for short- as for long distance operation. Automated private/shared vehicles operate mainly on open roads but in some cases also on restricted roads/lanes e.g. on the highway.
3. **Urban Mobility vehicles and buses:** This path covers 'Low Speed High Automation' for the urban environment. In specific areas in Europe today high automation in transit areas exist with specific solutions requiring low vehicle speed and/or dedicated infrastructure.

The specific developments for the three main categories of vehicles relevant here are listed in the following sections. Some further, cross-category applications, technologies and challenges are given as well.

Assessment of the short, medium and long-term impacts, benefits and costs of the deployment of automated vehicles is needed in order to make decisions related to investments on connectivity and automated driving. Higher levels of automated driving present a rupture in evolution of driver support and the whole driving task making the assessment of impacts of automated driving difficult and challenging as the changes in mobility itself (vehicle ownership and use, choice of residence, use of mobility services, use of travel time for different purposes, etc.) are likely substantial but hard to estimate ex-ante, and will affect all other impacts. The behaviouristic impacts will also be challenging due to need to get also sufficient empirical data on actual behaviour of automated vehicles in open traffic as results from simulators and models need empirical support for their transferability.

5.2.1 Automated Freight Vehicles

Implementing connected and automated driving in multi-brand and/or multi-fleet freight transport operation (including truck platooning) has great potential to improve (i) freight efficiency, (ii) safety and (iii) fuel efficiency in day-to-day logistics operation. This can be both on roads in mixed traffic situations and in confined areas. There are specific challenges related to the step from the currently lower levels of automation (L1-L2) to high level of automation (L4): Enhanced vehicle technologies for improved perception, control, connectivity, resilience and cost; harmonization and acceptance with other road users, infrastructure and logistics in mixed traffic on public roads; enhanced harmonized operation in port and terminals to optimize the complete logistic chain, in line with activities in the Topsector Logistiek[57].

Automated concepts can have a big impact on obtaining a safe and efficient last-mile urban logistics system. This will most likely be initiated via the implementation of end-to-end automated urban logistics solutions

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[57] https://topsectorlogistiek.nl/wptop/wp-content/uploads/2018/06/Meerjaren-digitaal.pdf

for waste collection, last-mile delivery, goods-on-vehicle consolidation and consolidation centres. This will demonstrate how highly automated (L4-L5) autonomy low-speed solutions can complement the existing high-speed transport networks for goods. There are already fully automated modular building blocks (mechanical and electrical) for autonomous transport units designed for scalability enabling maximum availability. Multi-stakeholder pilots need to be implemented, with possibilities for scaling up. Specific challenges here include:

- Address the operational needs and opportunities to increase efficiency, flexibility and reduce travel time and costs.
- Investigate the potential of combining automated urban delivery and people transportation.

5.2.2   Automated Passenger Vehicles

Passenger cars are the main driver of the development towards automated driving. Based on their high volume in the market, passenger vehicle manufacturers can afford to develop the necessary technologies. The vehicles are evolving stage by stage with more sensors, connectivity and computing power on- and off-board. Applications of these technologies can currently be distinguished by parking and driving use cases. Ongoing technological developments here focus on highway chauffeur, traffic jam chauffer, highly automated driving on limited speeds, highway convoy and highway autopilot.

Many technologies in SAE Level 0 of automation, also called warning and/or support systems, are in an established state. Examples include Lane Departure Warning, Cruise Control and ABS. For SAE Leve 1, examples include Adaptive Cruise Control, Stop & Go and Lane keeping assist. For these technologies, also when evolving further towards Level 3, there is a very clearly specified ODD. The systems are supporting the driver, and having the driver in control of the vehicle is essential. New support technologies will be brought up along the way towards further (inter)urban ADAS (Advanced Driver Assistance Systems), with geofencing as an emerging example. Human centric and user centric ADAS will play a key role.

For the next years, first large-scale tests and demonstrations with systems like Highway Autopilot are scheduled. Furthermore, gradual extensions of the ODD are needed.

Challenges included here are:

- Handle the transition of control.
- Driving in mixed traffic conditions, with road users equipped and not-equipped with connected and/or automated vehicle functions.
- Define and develop the essential digital and physical infrastructure to enable large scale deployment.
- Develop and define system architectures allowing scalability of ODD with increasing complexity.
- Advance and develop high precision localisation

5.2.3   Urban Mobility vehicles and buses

To speed up the technology take-up, there is a need to implement automation solutions in the current public transport system to increase efficiency and safety. Impaired and elderly users will for example require additional automation functions for convenience and safety. Large scale pilots of new Mobility as a Service concepts are needed for connected and automated vehicles together with innovative connected traveller services based on the needs both for urban and rural areas.

Developments on Personal Rapid Transport (PRT) solutions are to be included here, as well as urban shuttles (including People Movers), city-buses and coaches. PRTs are foreseen for initially last-mile solutions, with the potential for implementation also for longer distances in a next stage. The use of these types of vehicles also fits in the development to deliver flexible mobility services, offering tailor made solutions for the mobility system user.

Last mile logistics services need flexible, smart solutions as well. Mixed and combined transport of people and goods can be included. A gradual development is foreseen from implementation on dedicated lanes (and including e.g. geofencing), towards mixed traffic implementation and large-scale deployment; thus extending the ODD of the systems towards situations with increasing complexity.
The specific challenge here:

- Support the multi-stakeholder environment to stimulate innovation of the automated mass transport solutions for the future.
- Include the vehicles in the traffic flow combined with active modes of transport, with many interactions

5.2.4   Smart Traffic management

The enhanced, real-time data sharing should be used to enable a new approach for traffic management, taking a high-level systems approach. Routing and e.g. speed advices should well balance individual needs and collective needs, to lead to a transport system optimisation. This should also result in energy use optimisation, and emission reductions. The traffic management system will need to become more predictive, based on the current data and learnings from past events.

5.2.5   Sensor and perception systems, control systems

For Smart Mobility, and especially with increasing levels of automation, it is a prerequisite that the vehicle, in combination with the infrastructure, have a high level of reliability. Connected, cooperative, automated vehicles will continuously perform an iterative cycle consisting of Sense, Plan, and Act. The technology blocks, which have open challenges to reach ambitious levels of cooperative and automated mobility, are listed below.

- **Sense:** the vehicle should be equipped with a shared world model system consisting of the following building blocks:
  o Host tracking
  o Local fusion for target tracking
  o Road model, classification and context
  o Target motion prediction
  o Target classification
  o Global fusion for target tracking
  o Scenario generation for simulation

- **Plan:** the vehicle should be equipped with the capability to establish a Tactical Decision on the manoeuvres. The topics to be addressed include:
  o Route and mission planner
  o Vehicle behaviour for automated driving
  o Trajectory generation for automated vehicle
  o Detailed trajectory planner at lane level
  o Risk and situational assessment

- **Act:** finally, the vehicle should have also be equipped with the capability to actuate the manoeuvres requested by the tactical decision. This means that control on actuators requires improvements on:
  o Supervisory Control for (C)AD (incl. Transition of Control)
  o Fail-Safe + Transition of control
  o Functional Safety control for collision avoidance, fault-tolerant systems
  o Robust / Intelligent Longitudinal and Lateral Control (incl. interaction (V)RU)

       ○   Low level controllers on actuators (steering, braking, throttle)

Furthermore, the implementation of the macro areas Sense, Plan, Act, requires an "Integration and testing phase": the correlated activities do require an alignment to boost the implementation on the market as well as to improve harmonization and standardization.

The experiences gained in The Netherlands should be integrated in an EU methodology for the consolidation of the leading role NL presently has.

5.2.6 Connectivity

This section addresses trends and emerging issues and international discussions related to the connectivity for Smart Mobility. Topics range from deployment to big data.

5.2.6.1 Deployment

Despite several developments in the past, deployment is yet not mature as an eco-system, but is rather fragmented in ego-systems. The following is a list of challenges that will be considered to move towards deployment of Cooperative and Automated Systems

- Improve the penetration rate of equipment of road users connected to the digital infrastructure.
- (pre)deployment of communication technologies:
  - Harmonise architectures, standards and profiles;
  - Focus needed on development, testing and pre-deployment;
  - Necessary investments by the relevant stakeholders for large-scale testing and pre-deployment needed to realise the goals on traffic safety and efficiency, mobility, …
- Exploitation and development of test sites and pre-deployment sites on TENT network and cities
  - Reuse, interoperability and backward compatibility with existing technologies and services
  - Harmonisation with regional, national, local traffic management, organisation, regulation,

5.2.6.2 Big data handling

Connected Automated Mobility for new services and new domains will lead to an increased demand for connectivity. Therefore the following topics should be considered

- AI technologies, communication demands (larger / big data volumes, lower latencies, …
- Data sharing and storage for different service and use cases.
- New communication technologies (e.g. 5G).
  - V2X connectivity for safety related applications
  - RSU / MEC / edge computing
  - Slicing for CCAM services on long range cellular communication

5.2.7 Physical and Digital Infrastructure

Realization of smart mobility will need to be supported by road infrastructure solutions for those safe-critical situations falling beyond the present automated vehicle ODD, situations that are expected to happen both in urban- as well as in rural- environment.

The trends and needs for road infrastructure include:
- Improve the reliability of a digital twin of physical infrastructure supporting the autopilot of the vehicles. The digital infrastructure should also contain all relevant information needed by Traffic Manager

Provider to "influence" the autonomous vehicle in a safe mobility. A typical example is the situation of a CAV driving in a road work area with mixed white and yellow markers for old/new lanes. In case of accident, the traffic manager provided should be able to "support" the CAV for a tactical decision not foreseen by the mixed lane markers.

- o A link between road infrastructure element (physical and digital) with driving task (and especially to tactical decision approach) should be established.

  A prioritized list of road attributes will therefore support:

  - o the road authorities (to improve the quality and reliability of the prioritized physical and digital infrastructure attributes),
  - o the traffic manager (for them to improve actions when handling safe critical situations)
  - o the vehicle manufacturer (to adapt the V2X communication and the influence to/from the tactical decision layer, as well as to further improve the ODD of their automated vehicle)
  - o Improve the levels of Infrastructure Support for Automated Driving (ISAD), necessary to target SAE L4 level of Automated Vehicle. The expected solution will foresee the identification of the infrastructure elements needed to be adjusted and improved (both Physical and Digital) necessary to match the need of cooperative mobility.

5.2.8   AI

AI for situational awareness can help to make a huge step forward: estimate and predict the system state, human state and traffic state, the three parts that together determine the safety of a situation. This should then be taken a step further, from situational awareness towards cooperative, reactive, adaptive and predictive perception, decision making and actions. AI can be used for in-vehicle environment perception, decision making, risk assessment and situational predictions, as well as for predictions of e.g. energy consumption and charging planning.

5.2.9   Cross-theme applications and technologies

As applications and technologies can be used in a cross-theme context, the following paragraphs deal with the high light aspects.

5.2.9.1   Accident avoidance in future mobility scenarios

Safety challenges from new (multi-modal) mobility concepts need to be tackled for all road users including vulnerable road users and users of new vehicle types. For example, the digital detectability of two-wheelers (powered and non-powered ones) and pedestrians should be enhanced. Camera based solutions[58] are emerging, e.g. replacing mirrors at trucks and buses (See example Figure 18). The specific challenge is to investigate behavioural issues as well as the interaction between different road users, and to define methodologies to identify and model dedicated evaluation tools. The real-world performance of preventive systems needs to be monitored at the transport system level.

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[58] https://www.vdlbuscoach.com/nl/news/archief/camera-s-vervangen-buitenspiegels-innovatie-draagt-verder-bij-aan-ambities-vdl-bus-coach

Figure 18. Camera instead external mirrors

5.2.9.2 Future infrastructure for all road users' safety

Road infrastructure, both in urban and in rural areas, needs to be adapted to the requirements of new vehicle technologies, in particular automated driving functions. Its performance needs to be guaranteed by intelligent maintenance and monitoring. For pedestrians and cyclists focus should be on their dedicated infrastructure to avoid amongst others single vehicle / road user accidents. The specific challenge is to assess and secure that infrastructure design should take into account the need for interactions with all kinds of road users (human factors). Infrastructure includes here both the digital and physical infrastructure, as both are key to a wide deployment of connected and automated driving.

5.2.9.3 Development of security methods to cover safety threats for connected automated driving

Already today, cyber-security and vehicle safety functionalities are strongly linked due to continuously increasing connectivity. Higher levels of vehicle automation will further increase the need for secure electronic architectures significantly. On one hand, vehicle control will be automated: the human driver will not be enabled to intervene immediately in case of a cyber-attack. On the other, in many automation use cases, off-board data will be used for immediate driving decisions. The used data channels are potential entrance gates for attacks (2nd in focus of following topic). The challenge is to protect the electronics architecture from remote attacks in general and in particular for automation. To ensure accessibility and integrity of automated driving related data, these have to be constantly and reliably accessible and its integrity must be guaranteed.

5.3 Industrial manufacturing

Within the Automotive Industry, the challenge of climate neutrality has been driving manufacturing processes and the use of new materials. This has its impact upon the way one looks upon process related energy consumption and the use of natural resources. Next to that, efficient use of equipment contributes to the reduction of internal energy consumption and as such contribute to a reduction of the carbon dioxide footprint of the Dutch automotive industry.

5.3.1 Circularity as a prerequisite for climate neutrality[59]

In order to achieve climate neutrality, the synergies between circularity and reduce resource depletion and environmental impacts, not only directly in the factory but throughout the supply chains for components and materials. need to be stepped up by.:

- analyse how the impact of circularity on climate change mitigation and adaptation can be measured in a systematic way;
- improve modelling tools to capture the benefits of the circular economy on greenhouse gas emission reduction at EU and national levels;
- promote strengthening the role of circularity in future revisions of the National Energy and Climate Plans and, where appropriate, in other climate policies.

Next to reducing greenhouse gas emissions, achieving climate neutrality will also require that carbon is removed from the atmosphere, used in our industry without being released, and stored for longer periods of time. Carbon removals can be nature based, including through restoration of ecosystems, forest protection, afforestation, sustainable forest management and carbon farming sequestration, or based on increased circularity, for instance through long term storage in wood construction, re-use and storage of carbon in products such as mineralisation in building material.

To incentivise the uptake of carbon removal and increased circularity of carbon, in full respect of the biodiversity objectives, the Commission will explore the development of a regulatory framework for certification of carbon removals based on robust and transparent carbon accounting to monitor and verify the authenticity of carbon removals.

1. New products by new manufacturing systems
   - Net-shape and additive manufacturing
   - Product design using sustainable materials

2. Materials
   - Light weight
   - Bio-based
   - Circular economy

5.3.2 ICT[60] enabled intelligent manufacturing

Digitalisation is expected to have substantial impacts on cost of energy, both on CAPEX[61] (design improvement, industrial automation, . . .) and on OPEX[62] (predictive maintenance, remote operation services, . . .). The EU Industry 4.0 Initiative[63] expects that Big Data, Internet of things (IoT) Artificial Intelligence (A.I), 3D-printing and Robotics and Automated Systems (RAS) will reduce the cost, optimise the value chains and enable new business opportunities. The challenges for the industry will then be within the aspects of:

1. High Performance manufacturing and equipment
   - Flexible adaptive equipment, systems and plants
   - Flexible Line concepts (Process driven with capacity flexibility)
   - High precision manufacturing machines and systems

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[59] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN
[60] Information & communication Technology
[61] CAPEX: Capital Expenditures: the cost for development or delivery of non-consumable parts of a product or systeem
[62] OPEX: Operating Expenditures: de terugkerende kosten voor een product, systeem of onderneming.
[63] https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_PI4_AT_v2.pdf

- Tools for production planning and adaptive manufacturing systems
- Zero defects manufacturing

2. New products by new manufacturing systems
   - Net-shape and additive manufacturing
   - Product design using sustainable materials

5.3.2.1 Flexible adaptive production equipment, systems and factories

New system architectures with self-adaptive modular structures, machines and equipment that require less floor space can help achieve the requirements for intelligent manufacturing. Optimal flexible automation and improved HMI (human-machine interaction) developments will play an important role with respect to operational user adaptation.

5.3.2.2 High precision micro-production machines and systems

Future production technologies are moving towards producing parts with complex internal structures such as semiconductors and other parts with different material microstructures. Miniaturization and utmost precision of products and production equipment and integrated compact system designs will be important issues for this part of future integrated systems for the Automotive Industry.

6. Priorities and implementation

The previous sections sketched the context for future mobility by discussing the societal challenges with their corresponding legislative targets and technological trends. Sustainable and smart mobility are identified as the key themes. This section describes the main research priorities and development lines that are important for the Dutch automotive industry to strengthen its economic position and to accelerate developments that contribute to the missions specified in e.g. the Mobility Package defined by the European Commission, as well as the national knowledge and innovation agenda[64] [65].

Although in this roadmap trends and innovations in sustainable and smart mobility are described as separate development lines, we have to bear in mind that there is a growing amount of technological solutions, which are in both the smart and green domain. Examples are predictive cruise control, fleet optimization tools and predictive vehicle energy management. Furthermore, MaaS and various types of vehicle automation can contribute to reducing the environmental impact of passenger and freight transport, although this depends strongly on the way in which these innovations are applied and implemented and on possible rebound effects associated with their use. It is expected that in the near future the sustainable and smart domains converge more.

A fair part of innovation demands, identified in this roadmap, are related to the position of the Dutch automotive industry as manufacturer in the markets for heavy-duty vehicles and a wide range of niche vehicle applications. Innovation demands for this supply industry are derived from the developments that are foreseen in the European car industry.

6.1   Sustainable mobility

The roadmap section "Sustainable Mobility" directly contributes to mission D+ of the national Climate Agreement; zero emission and future-proof mobility for people and goods in 2050. Main focus of the Multi-year Mission-orientated Innovation Programs (MMIP 9 & 10) is on minimization of vehicle energy consumption and on concepts that enable the use of renewable energy carriers. In this roadmap, five key research domains are identified:

1. Current and next generation battery systems;
2. Highly efficient combustion engines;
3. Modular and high efficient powertrain components and systems;
4. Smart vehicle energy management and geofencing;
5. Advanced development tools.

These domains are in line with the MMIP focal areas, which are also listed in Section 1.1. Figure 19 illustrates that these research domains contribute to the various automotive application areas. This makes the roadmap section "Sustainable Mobility" robust for future developments. Consequently, the Dutch automotive industry is continuously preparing for the different pathways towards sustainable mobility. These domains will contribute to the international position of Dutch companies in both the light duty (LD) and heavy duty (HD) automotive market.

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[64] Innoveren met een missie, Integrale kennis- en innovatieagenda (IKIA) voor klimaat en energie
[65] Toekomstbestendig mobiliteitsystemen, https://topsectorlogistiek.nl/2019/10/14/deel-kia-toekomstbestendige-mobiliteitssystemen-2/

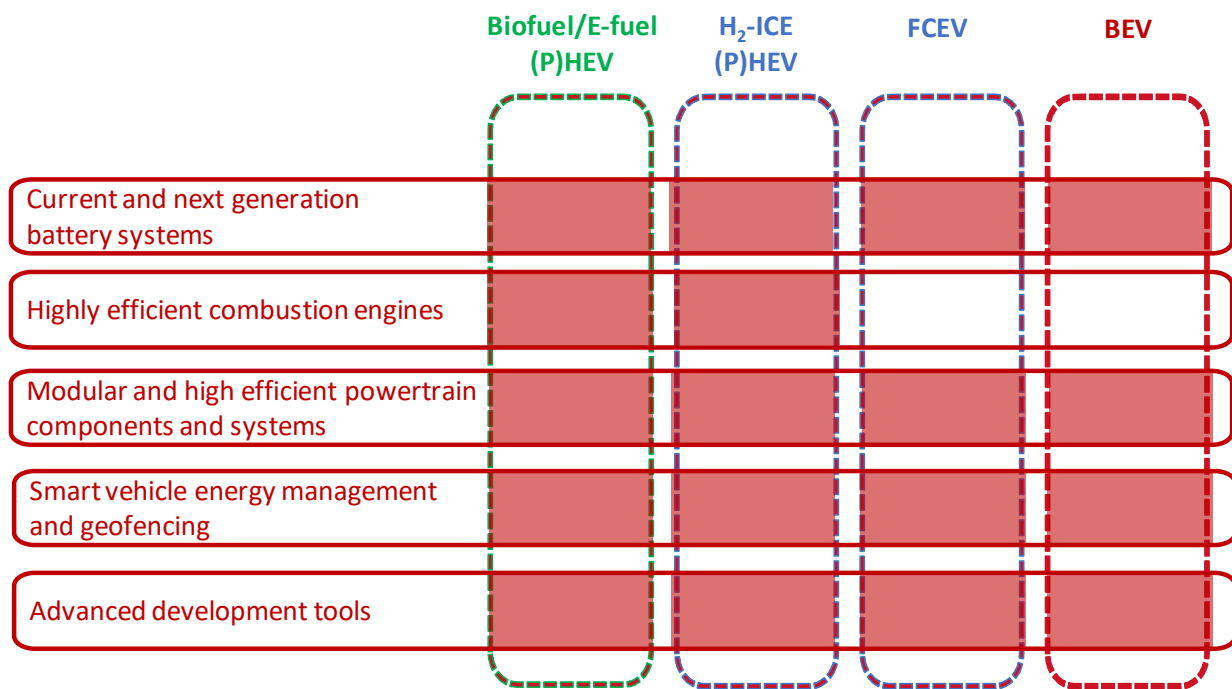|	Biofuel/E-fuel (P)HEV	H_2-ICE (P)HEV	FCEV	BEV
Current and next generation battery systems				
Highly efficient combustion engines				
Modular and high efficient powertrain components and systems				
Smart vehicle energy management and geofencing				
Advanced development tools				

Figure 19: Overview of development lines and their interconnection with energy transition pathways ((P)HEV: (Plug-in) Hybrid-Electric Vehicle; FCEV: Fuel Cell Electric Vehicle; BEV: Battery Electric Vehicle)

Future projects focus on these domains, and more specific to the topics mentioned for these domains in the following paragraphs.

6.1.1 Next generation battery systems

Battery technology is crucial for all pathways in the energy transition, see Figure 19. Besides electric vehicles (EV) and fuel cell vehicles (FCEV), hybridization of ICE-based powertrains will play an important role to meet requirements for zero emission zones. To improve energy density, TCO, and durability and to reduce usage of precious metals, the following development lines are important:

- Tools and methods to improve understanding, prototyping, and verification/validation facilities;
- Development of modular, reliable and cost-efficient battery packages for HD applications based on existing technology, including cross-application modular design;
- Understanding of real-world battery behaviour, incl. battery ageing, modelling, supporting both vehicle based control and operational care;
- Development of battery monitoring and diagnostics systems to e.g. predict performance, state of health or remaining useful life. Sensors and state estimation methods are integral part of this development;
- Novel sensors, thermal management and safety solutions;
- Battery management systems, incl. battery thermal control, fast charging functionality. Advanced communication and computational technology is required to develop scalable, modular battery management systems. Note that (powertrain) energy management is discussed in Section 6.1.4;
- Interoperable fast charging infrastructures, and charger technology;
- New materials and manufacturing methods to reduce weight or costs;
- New battery technologies: promising candidates are 3D structured batteries, solid-state lithium batteries, non-lithium batteries (e.g. sulphur) or those with zero cobalt, metal-air batteries, aqueous electrolyte batteries and redox flow cells;
- Innovations in battery design, production process and packaging with attention for life cycle performance and second life usage.

6.1.2 Highly efficient combustion engines

Internal combustion engines (ICE) will remain the primary power source for future heavy-duty powertrains in the upcoming decades. Developments are focusing on optimizing engine efficiency (towards 55% brake thermal efficiency) and enabling the usage of alternative and renewable fuels, ultimately leading to fuel flexible concepts. From a fuel perspective, bio-diesel, bio-ethanol and (bio) natural gas are interesting decarbonisation options on the short term. For long haul transport, synthetic and bio-based fuels, methanol, DME and OME are promising sustainable options on the mid- and long term. Recently, also H_2-ICE attracted much attention from Dutch industry, especially for non-road applications.

Collaborative research should concentrate on affordable design changes and concepts, which maximize fuel efficiency and minimize real-world pollutant emissions for ICE-based powertrains. This has to be realized without compromising TCO, reliability and durability. More precisely, the following key development lines are identified:

- Combustion system optimization is beneficial for all concepts; reduced heat rejection by using advanced materials, improved mixture formation by advanced air management (turbocharging, Variable Valve Actuation (VVA)) and advanced fuelling injection technology (multi-pulse injection, rate shaping);
- Development of H_2-ICE technology. Starting from engine demonstration of SI combustion concepts, research has to concentrate on reducing thermal loads, improve transient performance and minimize the need of aftertreatment systems from cost perspective. In a next phase, advanced combustion concepts, such as H_2-direct injection (DI), are of interest to maximize engine efficiency, enhance power density, and remove aftertreatment systems. Besides knock control systems, crucial enabler for all hydrogen applications is the availability of safe and efficient on-board hydrogen storage (350 bar, 700 bar and liquid H_2), especially for HD applications. Focus is on cost reduction;
- Development of advanced high efficient combustion concepts for mono-fuel (e.g. PPC, PCCI, SACI) as well as dual-fuel engines (e.g. HPDI, RCCI). Due to their ultra-low engine out emissions, these concepts potentially reduce system costs by minimizing the need for or by removing aftertreatment systems. Dual fuel concepts enable fuel flexibility by supporting the combination of a wide range of (renewable) fuels. Advanced fuel injection technology (incl. materials that withstand different fuels) and combustion control are essential technologies to enable fuel flexibility;
- Next generation energy recovery systems support all combustion concepts; e.g. optimization of (electrically-assisted) turbochargers (E-turbo), Rankine cycle, turbo-compound, and Thermal Electric Generator (TEG). This includes waste heat recovery systems for SI engines (using natural gas or H_2);
- High efficient and robust aftertreatment systems that enable low temperature, real-world operation. Maximal NO_x conversion (in advanced, lean-burn concepts) and CH_4 conversion (for lean-burn natural gas engines) by new catalyst formulations and advanced dosing systems. Advanced control strategies, such as fuel efficient thermal management, integrated engine-aftertreatment control, also play an important role and are discussed in Section 6.1.4;
- Real-world performance monitoring: sensors, Sensor-based Emission Measurement System (SEMS)), diagnostics, incl. state of health and remaining useful life;
- Improved understanding of the interaction of hydrogen and materials over a longer time period towards durability;
- Hybridization of ICE-based powertrain (see also Section 6.1.1), incl. impact of electrification on engine;
- Environmental impact assessment; well-to-wheel analysis, especially for renewable fuels.

6.1.3 Modular and high efficient powertrain components and systems

Highly efficient powertrain components and drivetrains contribute to reducing GHG emissions. Increasing the modularity of powertrain components and systems is an important route towards standardization and system cost reduction as well as for reducing development times for niche applications. Modularity includes standardizing form factors and harmonizing data exchange as well as power interfacing between modules. In addition, harmonised system control software is useful for easy connection of modular components into powertrain

systems. It also offers the possibility to implement control innovations related to predictive and adaptive energy management (see Section 6.1.4). Besides development of battery systems and combustion engines, which are discussed in the previous sections, the following specific development lines are identified:

- Development of innovative electric vehicle concepts in the non HD (e.g. L6/L7/M1 and N1) categories to support urban areas;
- Development of modular, energy-efficient components for electrified drivetrains (for x-EV applications);
- Development of energy-efficient electric auxiliaries, particularly for thermal management for buses, and those such as for utility vehicles and non-road mobile machinery;
- Integration of photovoltaic systems in vehicles;
- Development of fuel cell systems for HD applications, incl. system integration and "balance of plant" components, such as compressors and humidifiers;
- Development of high efficient native or distributed powertrains (incl. innovations on electric axles, transmissions, motors); this also enables new modular vehicle architectures, such as novel hybridization topologies including tractor/truck/trailer combinations;
- Data-processing methods for virtual testing, diagnostics, prognostics, and predictive maintenance;
- Mixed testing methods for accelerated development and functional verification/validation;
- Improved knowledge of assessment tools (such as VECTO), sharing of data and models in open development platforms.

6.1.4   Smart vehicle energy management and geofencing

Optimization of the efficiency of electrified powertrains and energy recovery applications requires energy management. Based on available information, these advanced control strategies optimize overall system performance by intelligent coordination of the various subsystems. Focus has been moving from powertrain towards vehicle level energy optimization. With the introduction of vehicle-to-infrastructure communication and platooning, increasing amounts of information from outside the vehicle will become available, such as mission, weather, route and traffic information and e.g. information on the availability of charging infrastructure along the route. Together with autonomous driving, these developments allow the introduction of new eco-driving functionality; further shift towards on-road vehicle energy efficiency optimization while meeting real-world tailpipe emission limits. With the introduction of zero emission zones, new integrated energy-emission management strategies are required for ICE-based hybrid-electric powertrains to realize geofencing concepts.

In the domain of advanced vehicle control, the following development lines are specified:

- Development of monitoring systems for diagnostics and control; combination of sensors and digital twins to estimate and predict vehicle system performance, state and health. New hybrid methods, i.e. combination of AI and physics-based modelling, and advanced controller hardware are at the core to enhance situation awareness. Sensor-based Emission Monitoring Systems (SEMS) that are accessible by independent legal parties are essential for enforcement of future emission management strategies, especially around zero emission zones. Powertrain component monitoring systems also allow the introduction of new condition-based maintenance concepts;
- Smart energy management for ultra-fast, high power battery charging methods and technologies, incl. battery thermal management, pre-conditioning, grid management;
- Development of geofencing concepts for hybrid electric vehicles; new integrated energy-emission management approaches that guarantee sufficient zero emission-driving range and meeting real-world emission limits outside the green zone. These approaches benefit from preview mission and route info. Advanced catalyst formulation and thermal management strategies are important enablers for enhanced low temperature performance;

- Development of predictive strategies for modular energy management that can deal with various powertrain configurations: innovative predictive control methods that exploit newly available preview route and traffic information. Due to increasing auto-calibration (or self-learning) capabilities, development times will be massively reduced. For on-line vehicle energy efficiency optimization, advanced control hardware, real-time modelling and optimization methods are key enabling technologies. Focus moves to an integrated vehicle approach that, besides the powertrain, includes the vehicle cooling system, heating, ventilation and air conditioning (HVAC) system and auxiliaries;
- Vehicle control system integration with Advanced Driver Assistance Systems (ADAS) and Automated Driving Functions (ADF) and with fleet- and traffic management; by taking the driver out of the loop. This opens new opportunities for smart energy management by vehicle velocity profile optimization. This is a next step towards energy management on platoon, fleet and traffic level. This will also require new pricing and taxing mechanisms.

All these development lines are characterized by a holistic approach. Consequently, demonstration of the overall system potential in real-world scenarios is a priority. More precisely, it is of utmost importance that new technologies can be integrated in the new VECTO tool for calculating CO_2 emissions from heavy duty vehicles.

6.1.5 Advanced development tools

Due to growing system complexity and the need for reduction of time-to-market and development costs, generic design, assessment and testing tools are crucial to support the development of new powertrain components, systems and controls. More precisely, focus is moving to real-world vehicle performance and there is a growing need to guarantee overall system performance under a wide range of practical operating conditions.

The following development lines are identified:

- Tools for design, optimization (incl. sizing) and assessment of powertrain and vehicle topologies with focus on vehicle energy efficiency and tailpipe emissions. Special attention is required to secure compliance with the HD CO_2-assessement method (VECTO) and with upcoming Euro-VII targets for future concepts. As a next step, these tools will move towards fleet and traffic system level;
- Total Cost of Ownership (TCO) and Life Cycle Analysis (LCA) benchmarking tools;
- New advanced testing and calibration methods. Mixed testing (i.e. combined virtual and experimental testing) for seamlessly integrated, multi-partner vehicle development. Real-world testing benefits from SEMS developments, as discussed in Section 6.1.4. In addition, integrated testing of smart and sustainable vehicle functions, new test cycle generation methods, and automation of testing and calibration based on machine learning methods are important enablers to reduce testing time and costs;
- Prototyping, pilot lines and living labs for demonstration of new technologies;
- Mobile and flexible charging and tanking infrastructure to support the testing of new energy carriers and technologies.

In Section 7.3, the Dutch automotive testing infrastructure is discussed in more detail.

6.2 Smart Mobility

The research effort in the Smart Mobility area focusses on the realization of reliable, efficient and safe mobility systems including Automated Driving, Connected and Safety. The innovation approach is depending on development of technology, products, systems and applications, piloting and demonstration of innovative technologies in specific use-cases or services showing the added value in the real-world, taking system aspects like behaviour, society, business and governmental policy into account. In general this implies a long and complex route with may stakeholders (private and public) involved.

In technological terms the advancement towards safe highly Automated Driving is seen as an evolutionary process to ensure that all involved stakeholders can develop and evolve with the adequate pace. This process already started with the development of anti-lock braking system (ABS), Electronic Stability Program (ESP) and Advanced Driver Assistant Systems (ADAS) and will progressively apply to more functions and environments. In parallel, driverless automated systems can be deployed to provide transport solutions in restricted areas with dedicated infrastructure or at specific locations e.g. ports and airports. Cars will be increasingly cooperative and connected, enabled by development and the integration of ICT solutions (more real-time, higher information density and custom fit), and as a further step, AI. The Automotive Industry is facing important challenges to enable or implement higher levels of Automated Driving (or more advanced ADAS applications for that matter) in all environments. It is utmost important that these challenges and existing gaps (technology, legislation, regulatory, acceptance, policy, etc.) are early recognized and appropriate measures are taken. The evolution of Autonomous Driving can be displayed in a timeline with different technologies set. Below in Figure 20. Roadmap example for Automated Driving deployment path for freight vehicles [ERTRAC 2019]. Figure 20 and Figure 21, examples are shown of how this evolution assumable will take place, respectively for the automated freight vehicles path as for the Urban Mobility vehicle path.
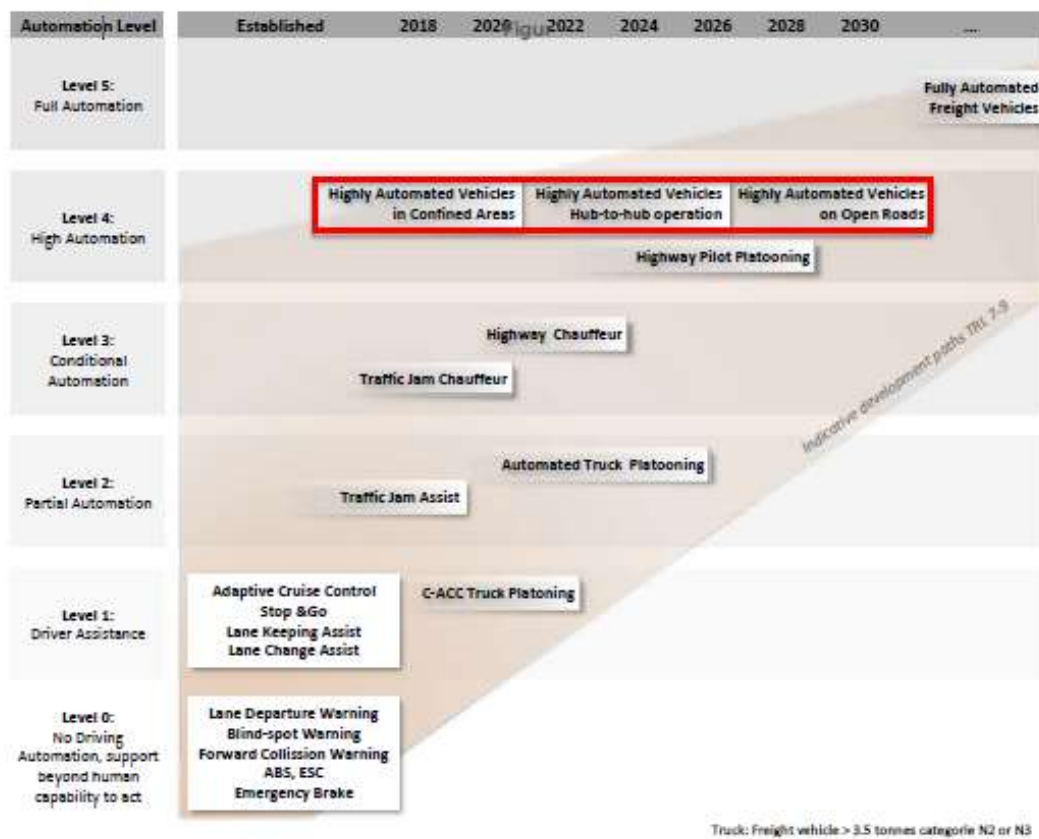
Figure 20. Roadmap example for Automated Driving deployment path for freight vehicles [ERTRAC 2019].

Within this Smart Mobility Roadmap, a set of technologies and related R&I activities is identified, for further development, enabling the application and implementation of connected, cooperative and automated mobility solutions on a wide scale. For sake of readability and simplicity, these technologies are grouped under one of the main themes (Cooperative Driving, Automation, Connectivity and Smart Mobility Services), with the best fit. Cross-theme application is key. The technological challenges and related R&I needs are given in the following sections.
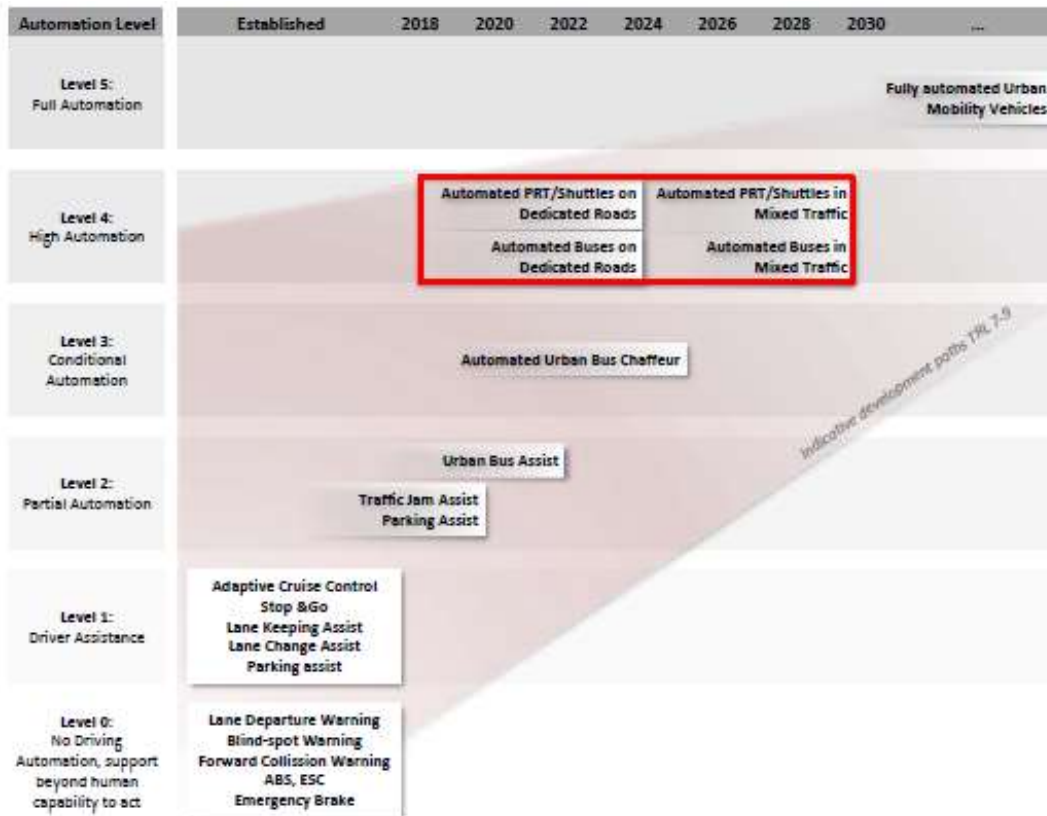
Figure 21. Roadmap example for Automated Driving deployment path for Urban Mobility vehicles [ERTRAC 2019].

6.2.1 Connected Cooperative driving

For this subtheme, focus is on upscaling, on multi-brand cooperation and interoperability. Safety and security are included, communication is an important enabler.

1. ADAS technologies (E.g. Cooperative Autonomous Emergency Braking)
2. Functional Safety with respect to impact of failure of V2V communication
3. HMI User Interface to support driver during cooperative driving
4. Cyber security and security for communication between vehicles and Cooperative Intelligent Transport Systems (C-ITS) (intruders, hackers)
5. Multi-brand heterogeneous Cooperative Automated Driving
6. Architecture and platform design including networked control (Improve Safety, efficiency etc.)
7. Digital infrastructure, Communication and Sensing Network
8. System architecture and framework for data sharing
9. Environmental awareness using V2X communication (Shared World Modelling), sensor fusion
10. AI based perception, decision making and actuation
11. Improved interaction with other (vulnerable) road users especially in urban areas
12. Develop and define system architectures allowing scalability of ODD with increasing complexity.

6.2.2 Automated driving

For this subtheme, the focus is on vehicle centric developments, including safety and security and with communication as an important enabler.

Aspects to be incorporated are:

1. Combined real-life safety assessment & virtual homologation using a selection of real world scenarios,

2. Functional Safety including robust and reliable system architecture for level 3 and level 4 automation, including the latest state algorithms for longitudinal and lateral control
3. HMI User Interface to lower driver workload and change driver behaviour,
4. High precision localization of host vehicle and other road users and connected vehicle world models,
5. Cyber security and security in vehicle and interaction with the surroundings and trust provisioning,
6. Environment Perception by on-board sensors (Sensor fusion combined with Vehicle World model),
7. Human factors and User interface (information load, transition of control),
8. Artificial Intelligence for CCAM solutions, including the related testing and validation of AI-based modules.

6.2.3   Connectivity

For the subtheme Connectivity, focus is on the increase of available and needed data, its handling and consequences of this increase and use of data.

1. New design of system to address in an integral approach all connectivity topics,
2. Data analytics, data storage and data sharing architecture to handle big data, supported by data value chains and service dominant multi stakeholder business models,
3. Predictive maintenance, of vehicles and infrastructure,
4. Security (Authentication) methods,
5. User centric Traffic management and traffic information, ,
6. Sharing services both for freight and passenger transport ,
7. Software lifecycle with over the air updates and alignment between software and hardware lifecycle.

6.2.4   Smart Mobility Services

For the subtheme Smart Mobility Services, focus is on the increase of ride sharing and sharing mobility means, as well as the planning and tailored offering needed, including multimodal approaches. Key challenges within this theme are:

1. Advanced connected car and automated driving technologies and concepts for personal mobility and transport.
2. Development of self-learning systems for e-vehicles (e. g., electric drives, energy storage systems) for improved availability and for remote maintenance, including smart pricing and transaction services.
3. Development robot taxi for personal urban mobility including the end-user service
4. Tools for providing sharing services both for freight and passenger transport
5. Personal Rapid Transport (RPT) systems featuring small automated vehicles operating on a network of classified infrastructure like (enhanced) bus lanes.
6. Enable use of vehicles in shared mobility services like MaaS (Mobility as a Service) and TaaS (Transport as a Service)
7. Investigate the potential of combining automated urban delivery and people transportation, explore hurdles and solutions

7. Relevant high-tech and automotive ecosystems

Due to the small size of the internal market, the innovation strategy of the Dutch automotive industry must be linked to the international demands in the green and smart mobility area. For traditional players, this is part of their natural strategy. For new players, especially in the disruptive technologies (i.e. electric powertrains, smart charging, Mobility as a Service, fuel cell technology) this is more difficult, but not less important. Next to invest in incremental technology. It is crucial for the Dutch economy to invest in those technologies which will have a big chance of economic success in the global market of the future. Therefore important for the realization of the roadmap is the potentially active role of the government. The cooperation on societal issues (mobility, environment and safety) can vary from interest to facilitator to partnership to even launching customer.

7.1 Cross-sectoral Cooperation

Because technological development occurs in an ever faster tempo and is ever more sector transcending, cross-sectoral collaboration is paramount. This is needed to share knowledge and to enhance technology development. Also in the case of technology transitions as in zero-emission city distribution (with topsectors Logistics, Energy and Creative Industry) or autonomous driving (Logistics, Agro & Food and Creative Industry).

Within the HTSM cluster there is, amongst others, cooperation with:

1. Business Cluster Semiconductors: Semiconductors have enabled most of the recent innovations in automotive technology, including vision-based, enhanced graphics processing units (GPUs) and application processors, sensors, and DRAM and NAND flash. As cars become even more complex, demand for automotive semiconductors will continue to rise steadily
2. Photonics: With a focus on intelligent electromechanical systems, the photonics based sensor technology will be integrated in mechanical parts requiring robust components for incar communications, monitoring, warning and vision. Optical equipment using e.g. LIDAR
3. Embedded Systems
   - Powertrain and Chassis Control: engine, automatic transmission, hybrid control, steering, brake, suspension
   - Body Electronics: instrument panel, key, door, window, lighting, air bag, seat belt.
   - Multimedia (Infotainment) Applications: car audio, car navigation, traffic information, electronic toll collection (ETC), back guide monitor.
   - Integrated Systems/Services: electronic stability control, pre-crash safety, parking assistance, lane keeping assistance.
4. High Tech Materials: advanced high strength steels, lightweight materials, composites
5. Smart Industry: additive Manufacturing, advanced manufacturing, robotics & mechatronics, high precision equipment, human machine interaction, smart design and engineering etc.
6. Solar: for roofs of busses and storage of solar fuels
7. Components & Circuits: application of micro- and nano-electronics in Sensors and Micro Electro-mechanical systems (MEMs), High-voltage and mains-connected applications and car batteries.

7.2 International Cooperation

At this moment, the main sales market for the Dutch automotive sector is Europe. Cooperation in innovation with European partners is a logical strategic choice. The Dutch automotive sector therefore participates in several European Programmes, such as Horizon 2020, Eurostars and Interreg (See A.5.1). AutomotiveNL made the choice to cooperate mainly with top technology partners, varying from OEMs, TIER suppliers, knowledge institutes and cluster organizations, in north-west Europe.

7.3 Test facilities and Living Labs

The Automotive Industry recognises the need for strengthening the innovation fundament. More precisely, this fundament consists of (see also [66]):

- Fundamental research;
- R&D support for small, medium and large companies;
- State-of-the-art facilities for testing, validation and prototyping, which are accessible for small, medium and large companies at acceptable costs;
- Living Labs;

Investments in new, shared facilities can be done through public-private partnerships involving knowledge institutes, companies and governments. Such investments are relevant for boosting the innovative strength of the Dutch automotive industry in both sustainable and smart technologies. In the area of sustainable technologies these facilities should include laboratory test facilities as well as on-road testing and monitoring. These facilities also play an important role in generating high quality data of (real-world) performance. In the area of smart technologies, test facilities require more embedding in the real-world, enabling ground-truth data gathering.

7.3.1 Sustainable Mobility Testing

For the development of sustainable vehicles, test facilities should include:
- Component and sub-system testing: battery, fuel cell, and fuel injection equipment;
- Single cylinder testing for combustion research and concept development;
- Engine testing for wide range of fuels (liquid fuels, natural gas, H_2) and (non)regulated emissions;
- Powertrain testing, including electrified powertrains and fuel cells;
- Vehicle testing – in laboratory: testing under varying ambient conditions, mixed testing (incl. simulation of various routes, geofencing and traffic flow), integration with smart testing (platooning, eco-route); - On the road: emissions (using Sensor-based Emission Monitoring System SEMS), incl. GHG/CO2.
- Large scale field labs for real-world data library of sustainable vehicles and smart grids;

To realize this, industry, research institutes and universities are teaming up in the following collaborative initiatives.

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[66] Meerjarige Missiegedreven Innovatieprogramma Duurzame mobiliteit,
https://www.klimaatakkoord.nl/documenten/publicaties/2019/11/07/mmip-9-en-10-emissieloze-mobiliteit

7.3.1.1 Innovation Centre for Sustainable Powertrains (ICSP)

Development of future powertrains requires an advanced innovation and test centre for testing and validation of components (such as batteries and fuel cells) as well as various powertrain and vehicle concepts. ICSP is an open and independent centre, accessible to industry, academic and governmental parties working in the field of powertrains and (sustainable) fuels [67]. This not only holds for on-road applications, but also for non-road applications. To assess performance under real-world conditions, facilities include climatic testing of batteries and a unique climatic-altitude chamber for powertrain and complete vehicle testing.

For the near future, ICSP will be upgraded with extended fuel infrastructure (including hydrogen. Also other fuels like methanol, DME, NH_3 will be considered), single cylinder research engine and advanced battery testing facilities.
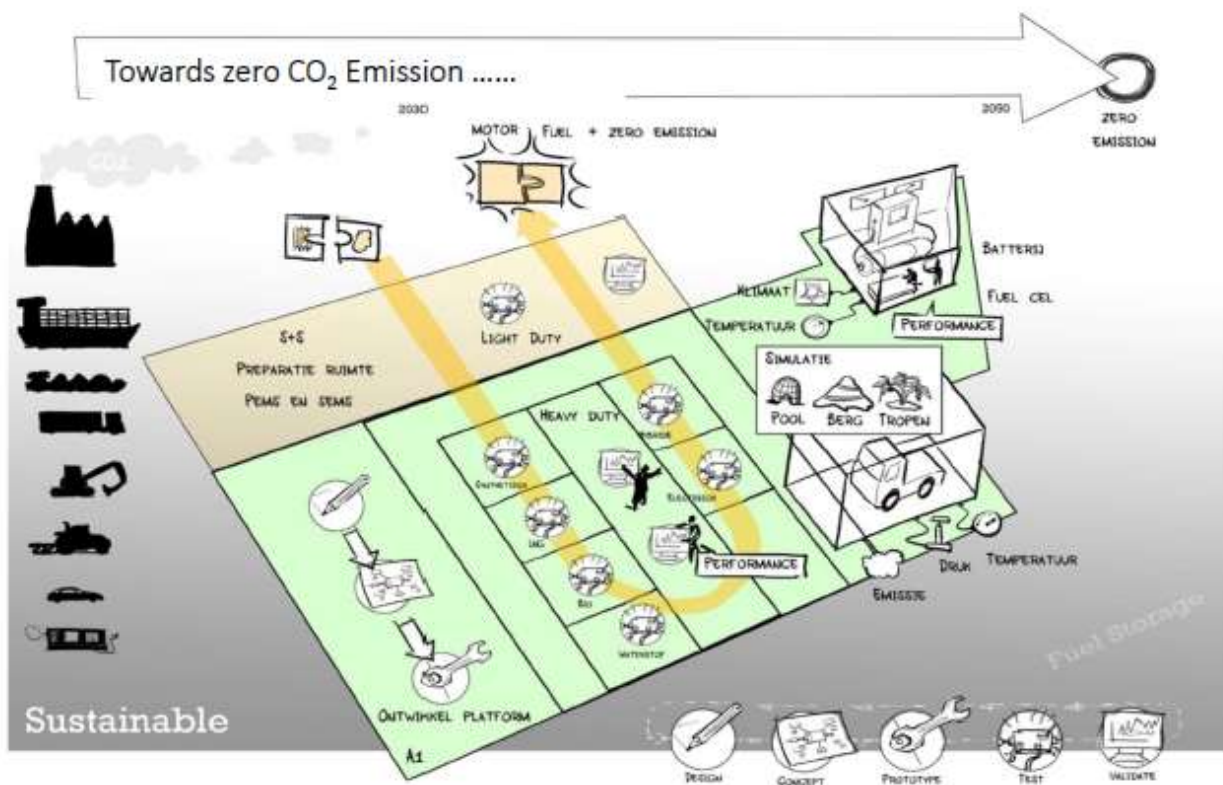
Figure 22. Schematic overview of ICSP facilities

7.3.1.2 Battery Competence Centre (BCC)

Originating from the Industrial perspective, the Dutch Automotive industry is mainly composed by Heavy-Duty vehicles (Trucks and Busses), which brings the focus upon the Niche Market of Heavy Duty Batteries. The Dutch Battery Competence Centre [68] has a focus upon the assembly of battery packs and with a living lab functionality. When looking upon the circularity of the Dutch economy of these batteries, the starting point is based upon social drivers derived from the European Climate agreement. In order to achieve a cross sectoral approach to maximize volume, the users of Heavy-Duty batteries are strongly depending upon the provision of battery cells. These cells, mainly produced in Asia (China, and Korea), identify the limitation of economical and technological control within

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[67] https://icsp-helmond.nl/nl/
[68] In formation, to be operational in 2021

Europe and as such the Netherlands. As Non-European countries control the Mining of raw materials (Lithium, Cobalt) in Africa, and their internal focus shifts towards LEV, the question of their adaptation towards Heavy Duty performance improvement of cell technology becomes questionable for the future. In order to re-take control and improve the Global footprint with respect to the circular economy of Heavy Duty Batteries, the research for alternative raw materials and/or new battery technology can be a future activity.

For battery technologies, it crucial that Dutch innovations are connected to European research and development programmes to enable integration of Dutch technologies in products for the European and global market. Essential for the development of new battery technology in the Netherlands, from low to higher TRL-levels, are test facilities and access to pilot production facilities.

7.3.1.3   TU Eindhoven Automotive lab

Starting from 2020 onwards, the Automotive lab facilities are undergoing a renewal, in an overall renovation programme. A control room with several test rigs will be included, like there is already, as well as four areas with specific use in testing and R&D activities:

- " garage": car lifts, heavy-duty chassis dynamometer;

- " showroom": e.g. TruckLab , vehicle demonstrators, driving simulator;

- Test cells for component testing (e.g. continuously variable transmission (CVT), tires, shock absorbers);

- "Zero Emission lab" with set-ups for spray characterization of new sustainable fuels and fuel injection equipment and engine testing (incl. optical single cylinder and dedicate multi-cylinder engine). Facilities need to be prepared for hydrogen testing.

7.3.2   Smart Mobility Testing

In the field of Smart technologies test facilities should include:
- Vehicle testing – lab: ambient conditions, mixed testing (traffic, platoon) / on-road: emissions (SEMS, incl. GHG/CO2). Integration with smart testing (platoon, eco-route)
- Lateral Support Systems:
  - Lane Keeping System
- Lane Centring including e.g. Lane change and Blind Spot recognition
- Longitudinal Support Systems:
  - ISA / Speed Alert
  - Cooperative Adaptive Cruise Control
  - Autonomous Emergency (Fall back) Braking Systems
- Recognition and detection of:
  - Traffic sign recognition
  - Traffic light status detection
  - Crossing and inserting traffic detection
- Effects on system level (throughput, emission effects), traffic management
- Human behaviour in smart mobility, including transition of control, interactions between equipped and non-equipped road users

An important project and activity combining smart mobility testing facilities over regions, is the UMO initiative [69]. The Urban Mobility Observatory (UMO) is an extensive system of sensors and IT infrastructure to observe mobility and travel behaviour and to combine data from different types of measurements (cameras, mobile phone, surveys). In UMO, all kinds of traffic, transport and mobility data will soon be collected, stored and made available for research into mobility and transport in urbanized regions. Parties like TU/e and TUD are engaged.

7.3.2.1   Smart Mobility Living lab Helmond-Eindhoven

A kilometre-long real-life test environment, located between Helmond and Eindhoven, equipped with cameras, transponders and WiFi beacons, 5G, and connected to a high-end control room, the Traffic Innovation Center, provides facilities for operational testing of vehicle, traffic and roadside system testing.

Figure 23. Living Lab highway A270 Automotive Campus

In the Living Lab, establishing e.g. a ground truth, but also initial digital twinning, are in the key areas of TU/e inputs, and ongoing developments for the coming years. This is needed for R&D activities as indicated in the roadmap –and beyond- as well as validation testing. TU/e is using several test vehicles in these developments.

7.3.2.2   ICADI testing with (ultra) big data

ICADI[70] is an open partnership of prominent and notable organizations from the Automotive supply and knowledge domain. Thus to collaborate in the areas of (ultra-big) data, knowledge and technology. This ranges from standardizing data formats from vehicles, data accuracy in time and space, data-reduction and scenario-building, to functional safety and homologation aspects. All this in order to prepare for a new reality in which (masses of) data from a driving fleet of vehicles, combined with data from infrastructure, are used to improve both traffic management and road safety, as well as to lay a foundation for the next generation of smart vehicles.

The aim is to increase and strengthen the Connected Automated Driving (CAD) knowledge base and ecosystem. Specifically, to connect the existing knowledge and technology from the partners with both physical and data infrastructures. Through this, the development but also application of CAD vehicles will contribute to defining a 'ground-truth' in the CAD domain. Accelerating future mobility solutions and making these available for use will allow us to contribute to a safer and more efficient mobility system. ICADI not only lays out the foundation for the future, we also make the future a reality.

Rather than starting from scratch, the broad and extensive experience of partners in the areas of mapping, sensing, computing, communication technology, testing and simulation, and CAD applications, will form the solid base on which ICADI will build. On top of this, combined experience in collecting and processing data, safe highway testing (including obtaining the necessary testing permits) and more, gives ICADI a head start.

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[69] https://www.tudelft.nl/2018/tu-delft/umo-van-start-onderzoek-naar-mobiliteit-in-stedelijke-gebieden/
[70] https://icadi.net/

7.3.2.3 TU Delft Research lab

At the TU Delft several Living Labs are installed for testing innovations related to autonomous driving testing in public domain conditions;

- **Research lab Automated Driving Delft (RADD)[71]**
  Facilities to test products, concepts or models and to observe traffic in a range of environments varying from a closed environment (enclosed test site, test track) and a semi-closed environment at The Green Village, to testing on public roads and on and around the TU Delft campus.
- **Research lab Autonomous Shipping Driving Delft (RAS)[72]**
  Following Autonomous systems with a vehicle origin, Testing of themes such as the autonomous passing of bridges and locks, autonomous construction and departure, sailing with multiple (autonomous and non-autonomous) ships, platooning and the influence on CO_2 reduction.

7.4 Automotive Learning Community

The Dutch Automotive Industry has a unique position in developing an intelligent, innovative solutions to global challenges. A well-trained workforce is one of the main pillars for this. To remain at the top, we must make a permanent effort and respond promptly to what is happening in our environment. We want to make innovations pay off quickly in business and education. This requires smart organization of innovation, collaborative sharing of knowledge, e.g. from fundamental research and living labs. Automotive has its own position and responsibility with its Human Capital agenda. We want to ensure that we continue to invest in education and training in areas that are crucial for the Netherlands and the Dutch Automotive Industry. Not side by side but with each other.

7.4.1 The time of transition

We are currently facing major challenges in the labour market. Exceptional economic developments, societal challenges and transitions in technology, digitization, robotization, climate and climate adaptation require an agile response on the labour market. Organizations are organized differently, old jobs and tasks are replaced by new ones and the content of the work changes. In order to maintain our global top position and realize our ambitions for the societal challenges, we must continue to invest in our well-trained workforce and commit ourselves to providing all talent with a place on the labour market.

7.4.2 Smart organizing innovations, working and learning

The mentioned transitions require agility. We want innovations to pay off quickly in practice, for companies and education to be able to apply them quickly and for people to be adequately trained and equipped for this. That is a matter of smart organization by organizing innovation, working and learning in close proximity. We call this concept a learning community.
Through the TALCOM[73] (The Automotive Learning Community) project, we will be giving shape to this in practice in the coming years, among other things via the Automotive Centre of Expertise. But of course also in numerous Field Labs, Skills Labs, Centres for Innovative Craftsmanship, professorships and practitioners with a focus on MBO and HBO and learning in companies.

It is necessary that we continue to unite the partners in the triangle of business, research and education. Organize short lines of policy and management and, together with our partners, quickly convert plans into practical

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[71] https://www.thegreenvillage.org/projects/researchlab-automated-driving-delft-radd
[72] https://rasdelft.nl/

[73] *The Automotive Learning COMmunity (TALCOM) applicatie, Roadmap Human Capital Topsectoren 2020 – 2023*

activities. Boundaries between sectors are blurring and social issues make a broad appeal to the collective human capital approach of the top sectors together. That is why we also focus on joining forces and as Automotive and HTSM we look beyond our own borders. The Dutch top sectors are also joining forces to work on this together over the next four years.

8. Priorities

This section presents an overview of priorities in time. Three time blocks have been defined to guide the main drivers on short, mid and long-term. Following the list, the next chapter addresses the investments in relation to this roadmap.

Legend: Green | Smart | Manufacturing

Priorities in time	< 2025	2025 - 2030	> 2030

Drivers (societal/economic)
- ❶ CO2 legislation for on-road applications
- ❷ Energy transition towards green electricty, green H2 and E-fuels
- ❸ Zero emission public transport (NL Climate Agreement)
- ❹ Zero emission cities (NL Climate Agreement, MMIP)
- ❺ Impact Circularity & Life cycle assesment
- ① Vision Zero Casulties
- ② Call for urban transitions: more shared space

Applications

Passenger car
- ❶ Optimization EV towards affordability and circularity
- ❷ Smart electric grid for x-EV
- ❸ Long range EV by new battery technology
- ① Human centric ADAS, including interaction with vulnerable road users
- ② Increased ODD ADAS
- ③ Increased ODD autopilot
- ④ Fully automated passenger cars

Urban mobility solutions (busses & PRT)
- ❶ Optimization EV towards affordability and circularity
- ❷ Optimization FCEV towards affordability and circularity
- ❸ Long range EV by new battery technology
- ① Urban ADAS (Driver and safety oriented)
- ② New urban+ mobility concepts

Long haul (heavy-duty)
- ❶ Highly efficient hybrid-electric vehicle concept for geofencing
- ❷ Zero-emission vehicle concept based on H2-ICE
- ❸ Zero-emission vehicle concept for E-fuels
- ❹ Optimization FCEV towards affordability and circularity
- ① Highly Automated Vehicles in Confined Areas
- ② Highly Automated Vehicles Hub-to-hub operation
- ③ Highly Automated Vehicles on Open Roads

Enabling Technology
- ❶ Current and next generation battery systems
- ❷ Sensor-based monitoring & diagnostics for Emissions, Fault Detection & Predictive Maintenance (AI & geofencing)
- ❸ Highly efficient ICE (for E-fuels and H2)
- ❹ Modular and high efficient powertrain components and systems
- ❺ Smart, adaptive vehicle energy management (AI & Geofencing)
- ① Cybersecurity
- ② Reliable maps, new functional layers
- ③ Advanced sensortechnology for ADAS+ (radar based)
- ④ High precision localization of National road users
- ⑤ High precision localization & detection of vulnarable Urban roadusers (including infrastructure based)
- ⑥ Advanced communicationtechnology for C-ADAS+ (including 5G)

Validation / roadworthiness
- ❶ Advanced lab facilities for sustainable vehicle development & validation (BCC, ICSP H2 capabilities, ZE-lab)
- ❷ Large scale field lab for real-world data library of sustainable vehicles & smart grids
- ❸ Advanced virtual lab facilities for sustainable vehicle development (Vehicle-in-the-loop, simulated traffic & V2X)
- ① Ground truth infrastructure including capability of testing and validation of AI-based modules
- ② Digital infrastructure, Communication and Sensing Network System architecture and framework for data sharing
- ③ Virtual homologation

Manufacturing & Materials
- ❶ New products by new manufacuring systems, high volume additive manufacturing
- ❷ High performance manufacturing and equipment towards zero defects production (RAM)
- ❸ ICT enabled and intelligent manufacturing towards autonomous plants
- ❹ Sustainable manufacturing towards circular production

Abbreviations as used:

ADAS	Advanced Driver-Assistance Systems	BCC	Battery Competence Centre
ICE	Internal Combustion Engine	ICSP	Innovation Centre for Sustainable Powertrains
ODD	Operational Design Domain	RAM	Reliability Availability Maintainability

9. Investments

All data refer to contributions of the stated parties in public-private collaborations of any kind in relation to this roadmap, including but not limited to contract research, public funded national and international projects, and TKI-related activities. The figures requested are annual cash flow, including the value of in-kind contributions, not the multi-annual commitments stated in that year. The contributions in the (lower) European agenda are considered to be included in the (upper) overall agenda of the roadmap. R&D in public-private partnership, including contract research; all figures in million euro cash flow per year (cash plus in-kind contribution).

* Values in the table below are in Million Euro (M€).

Roadmap	Industry	TNO	NWO	Universities	Departments[1] and regions[2] (excluding TKI)	Grand total
2020	12	6	1.5	10	1.5	**28**
2021 *	12	6	1.5	10	1.5	**28**
2022 *	12	6	2	10	2	**32**
2023 *	13	6	2	11	2	**34**
2024	13	6	2	11	2	**34**
2025	13	6	2	11	2	**34**
2026	13	6	2	11	2	**34**
2027	13	6	2	11	2	**34**
2028	13	6	2	11	2	**34**
2029	13	6	2	11	2	**34**
2030	13	6	2	11	2	**34**
European agenda within roadmap	**Industry**	**TNO**	**NWO**	**Universities**	**EZK co-financing of European programs**	**co-financing of European programs[1]**	**Grand total**
2020	6	2.2	0	7	1	5.3	14
2021 **	6	2.2	0	7	1	5.5	14
2022 **	7	2.2	0	8	1,5	5.5	16,5
2023 **	7	2.2	0	8	1,5	6	22,5
2024	7	2.2	0	8	1,5	6	22,5
2025	7	2.2	0	8	2	6	23
2026	7	2.2	0	8	2	6	23
2027	7	2.2	0	8	2	6	23
2028	7	2.2	0	8	2	6	23
2029	7	2.2	0	8	)2	6	23
2030	7	2.2	0	8	2	6	23

Table 2. Annual contributions to public-private collaborations

* Green/Smart Transport Delta might impacted the values , If the budget for University rises, the related investments from Industry will then also rise.
** European RRF (Recovery Resilience Facility) funding, providing an additional boost, has not been included (5.8M€ NL)

A.1.1 List of abbreviations

This annex contains the listing of definitions and abbreviations as used within this document.

ACE	Automotive Centre Of Excellence
ADAS	Advanced Driver Assistance Systems
AI	Artifical Intelligence
CCAM	Cooperative, Connected And Automated Mobility
ECU	Electronic Control Unit (Also Engine Control Unit)
EM	Electro Magnetic Emission Levels
ERS	Electric Road Systems
GHG	Greenhouse Gas
HTSM	High Tech Systems & Materials
ICE	Internal Combustion Engine
IoT	Internet Of Things
LCA	Life Cycle Analysis
MaaS	Mobility As A Service
MMIP	Multi-Year Mission-Orientated Innovation Program
MMIP	Multi-Year Mission-Oriented Innovation Plan
NVM	Nitrogen Emission Levels
OEM	Original Equipment Manufacturer
ODD	Operational Design Domain
PEMS	Portable Emission Measurement Systems
R&D	Research And Development
TaaS	Transport As A Service
TALCOM	The Automotive Learning Community (TALCOM)
TCO	Total Cost of Ownership
TIER	Suppliers In Chain
VECTO	Vehicle Energy Consumption Calculation Tool
ZE	Zero Emission

A.2.1 Applicable and reference documents

1) Applicable documents

This section presents the list of applicable documents. A document is considered to be applicable if it has precedence over the current document.

[AD-1]   European (Paris) Climate Agreement, (COP21), December 2015

[AD-2]   National Climate Agreement – The Netherlands, version of June 28th, 2019.

2) Reference documents

This section presents the list of reference documents. A document is considered to be a reference if it is referred to however has no precedence over the present document.

[RD-1]   RANKING EU PROGRESS ON ROAD SAFETY, 13th Road Safety Performance Index Report

[RD-2]   https://www.rvo.nl/onderwerpen/innovatief-ondernemen/topsectoren

[RD-3]   https://www.klimaatakkoord.nl/documenten/publicaties/2019/11/07/mmip-9-en-10-emissieloze-mobiliteit

[RD-4]   The Automotive Learning COMmunity (TALCOM)

[RD-5]   https://www.investopedia.com/insights/worlds-top-economies/

[RD-6]   https://www.raivereniging.nl/automotiveindustrynl

[RD-7]   https://opendata.cbs.nl

[RD-8]   vehicles are communicating with each other and/or with the roadside

[RD-9]   vehicles are equipped with technologies that enable them to act automatically independent of other vehicles or traffic management

[RD-10]   vehicles exchange information with the cloud

[RD-11]   https://ec.europa.eu/transport/themes/strategies/news/2020-02-03-commissioner-valeans-speech-eu-strategy-mobility-and-transport_en

[RD-12]   https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[RD-13]   https://ec.europa.eu/transport/themes/strategies/news/2020-02-03-commissioner-valeans-speech-eu-strategy-mobility-and-transport_en

[RD-14]   https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

[RD-15]   White paper, https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en

[RD-16]   https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[RD-17]   Communication from the Commission to the European parliament, A roadmap for moving to a competitive low-carbon economy in 2050

[RD-18]   https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/06/28/national-climate-agreement-the-netherlands/20190628+National+Climate+Agreement+The+Netherlands.pdf

[RD-19]   EU Revised Renewable Energy Directive, https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii

[RD-20]   https://etsc.eu/euroadsafetydata

[RD-21]   https://ec.europa.eu/commission/presscorner/detail/en/QANDA_20_1004

[RD-22] https://etsc.eu/euroadsafetydata/

[RD-23] https://etsc.eu/euroadsafetydata/

[RD-24] Roland Berger

[RD-25] F. Willems. P. van Gompel, X. Seykens & S. Wilkins, 2018, Robust real-world emissions by integrated ADF and powertrain control development, Book Chapter, Control strategies for advanced driver assistance systems and autonomous driving functions : development, testing and verification. Waschl, H., Kolmanovsky, I. & Willems, F. (eds.). Springer, p. 29-45

[RD-26] https://www.raivereniging.nl/artikel/nieuwsberichten/2020-q2/0406-focus-document-and-action-plan-automotive-manufacturing.html

[RD-27] ISO 50001:2018

[RD-28] UN Intergovernmental Panel on Climate Change (IPCC) - https://www.ipcc.ch/report/ar5/wg3/

[RD-29] https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

[RD-30] https://blog.ifs.com/2017/12/do-we-have-to-rethink-the-future-of-mobility/

[RD-31] https://www.acea.be/press-releases/article/getting-to-the-green-deal-dont-rule-out-alternative-fuels-with-a-track-reco

[RD-32] CONCAWE, https://www.concawe.eu/publication/role-of-e-fuels-in-the-european-transport-system-literature-review/

[RD-33] https://h2.live/en

[RD-34] https://saemobilus.sae.org/content/j3016_201806

[RD-35] https://www.vdlbuscoach.com/nl/news/archief/camera-s-vervangen-buitenspiegels-innovatie-draagt-verder-bij-aan-ambities-vdl-bus-coach

[RD-36] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

[RD-37] CAPEX: Capital Expenditures: the cost for development or delivery of non-consumable parts of a product or systeem

[RD-38] OPEX: Operating Expenditures: de terugkerende kosten voor een product, systeem of onderneming.

[RD-39] https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_PI4_AT_v2.pdf

[RD-40] Innoveren met een missie, Integrale kennis- en innovatieagenda (IKIA) voor klimaat en energie

[RD-41] In formation, to be operational in 2021

[RD-42] https://icadi.net/

[RD-43] The Automotive Learning COMmunity (TALCOM) applicatie, Roadmap Human Capital Topsectoren 2020 – 2023

[RD-44] Ministries, excluding contributions to TKI HTS

[RD-45] Regional and Local Authorities

[RD-46] Ministry of Economic Affairs contributions to JU ECSEL and EUREKA clusters

[RD-47] https://www.electricitymap.org/zone/NL

A.3.1 European Roadmaps

The Dutch Automotive Industry is closely connected to the European research agendas. 88% of the turnover of The Dutch Automotive Tiers comes from Europe [ING 2015], whereas this percentage for e.g. DAF Trucks is 90 %. Next to this, it is clear that the automotive industry is a global industry and it is crucial that the Dutch automotive industry is closely connected to the international automotive communication community.

For Europe the automotive industry is of major importance because 5.3% of the EU employed population – comes from the automotive sector. Furthermore, 10% of EU's manufacturing employment is within the automotive sector, including its supply chain. The sector is a key driver of knowledge and innovation, representing Europe's largest private contributor to R&D, with over €41 billion invested annually [ERTRAC 2019]. The automotive sector contributes positively to the EU trade balance with a €92 billion surplus.

There are several European platforms active in the field of bringing stakeholders together and develop common visions, as described below.

1) ERTRAC

The European Road Transport Research Advisory Council (ERTRAC) is the European technology platform that has set out several key ambitions in its Strategic Research Agenda [ERTRAC 2018], namely:
1. The European road transport sector should be 50% more efficient in terms of decarbonization by 2030 (compared to 2010);
2. New fuels will enter the market;
3. Transport schedules (mobility) will be 50% more reliable;
4. Traffic safety will improve significantly reducing fatalities and severe injuries with 60% by year 2030 (baseline 2010).

Two ERTRAC roadmaps are prominent for European policy deployment and automotive research in the coming decade to reach this.

The ERTRAC Energy Carriers for Powertrains Roadmap [ERTRAC 2019b] states that within the transport sector three main GHG reduction routes are available that can contribute to meeting the target:

1. Improving the energy efficiency of vehicles, specifically of internal combustion engine vehicles by more efficient engines and powertrains, weight reduction, improved aerodynamics and a range of other measures;
2. Application of alternative, low CO_2 energy carriers, such as electricity, hydrogen or synthetic methane from renewable sources, and gaseous and liquid biofuels;
3. Behavioural measures including energy efficient driving styles, improved logistics and curbing the growth of travel demand.

The ERTRAC Road Transport Safety & Security Roadmap states that within the transport sector three main routes are available that can contribute to meeting the safety target:

1. Continuing in research on passive and active safety and enforcement of traffic rules
2. Strong effort in preventive safety, both at vehicle and infrastructure level as for protection of vulnerable road users.
3. Integrated and cooperative safety to provide the needed level of "protection and perception" to ensure to drive always with enough margin avoiding sudden problems, like vehicle failure or static obstacles in the road.

2) EGVIA and 2Zero

The European Green Vehicle Initiative Association (EGVIA) is a contractual Public-Private Partnership (PPP) involving industrial, research, and the European Commission in defining research funding for electrified and alternative fueled vehicles. EGVIA shares several of the ERTRAC targets, with specific focus on their realization via Green Vehicle initiatives. EGVIA aims to continue under Horizon Europe as the 2Zero Partnership. The 2Zero partnership focuses explicitly on funding BEV and FCEV based concepts, although the SRIA considers other powertrains (e.g. hybrid).

This group interfaces with other PPPs, such as Batteries Europe, Clean Hydrogen, and CCAM.

3) Batteries Europe (incl. Batteries 2030+)

The European Batteries Europe considers the SRIA around the research, development, production and recycling on batteries for both mobility and stationary storage. Originally part of cross-cutting research in the latter stages of H2020, within Horizon Europe, it is positioned as its own Work Programme and PPP.

This group primarily looks after the European research agenda, and has links to the industrially-led Battery Alliance.

4) Clean Hydrogen (formerly FCH JU)

The Clean Hydrogen IPPP is driven from the Hydrogen Europe and Hydrogen Europe Research groups and focuses both on transport, as well as the energy topics around hydrogen production and use. Clean Hydrogen mainly concerns itself with the use of hydrogen through fuel cells, and is a direct continutation of the FCH JU (Fuel Cell Hydrogen Joint Undertaking).

This group looks after the research agenda, and is linked through the board to the industrially-led Clean Hydrogen Alliance.

5) EARPA

The European Automotive Research Partners Association is the network of research partners within European under the domain of automotive research. This network positions the research partners' research agenda via several Position Papers on e.g. sustainable mobility, energy and engines and connected, automated and safe driving

6) EUCAR

The European automotive vehicle manufacturers cooperate under the umbrella of EUCAR to fulfill their mission to "Strengthen the Competitiveness of the Automotive Manufacturers through Strategic Collaborative Research & Innovation". EUCAR has identified the main priorities for collaborative research and innovation (R&I) in the automotive sector with the main objectives to be targeted for collaborative automotive R&I in the domain.

7) EPoSS

A common European Platform on Innovative Smart Systems Integration from research to production is provided by 'EPoSS'. It defines priorities for common research and innovation in the future, formulates commonly agreed road maps for action, provides a Strategic Research Agenda, mobilizes public and private resources, and supports its members in coordinating their joint research efforts and improving communication amongst the members as well as towards the European Commission. EPoSS is an industry-driven policy initiative, defining R&D and innovation needs as well as policy requirements related to Smart Systems Integration (SSI) and integrated Micro- and Nanosystems. EPoSS is contributing to the Europe 2020, the EU's growth strategy, to become a smart, sustainable and inclusive economy.

The above-mentioned roadmaps / visions together with the "SER-brandstoffenmix vision" [SER 2014] has led to the HTSM Roadmap Automotive 2020-2030. This strategy will allow Dutch companies and knowledge institutes to excel in specific innovation areas. The strategy leverages the strength of the Dutch industry and potential synergy effects of the EU automotive ecosystem.

A.4.1 HTSM Roadmaps

HTSM roadmaps can be found at: https://www.hollandhightech.nl/htsm-roadmaps

Advanced Instrumentation	
Aeronautics	Photonics
Automotive	Printing
Electronics	Security
Healthcare	Semiconductor Equipment
High Tech Materials	Smart Industry
Lighting	Space
Nanotechnology	Systems Engineering

A.5.1 European Programs

1) HORIZON 2020 and Horizon Europe

For the Horizon 2020 program a number of institutions are working on road mapping and positioning subjects important for Dutch industry. Dutch partners are actively involved in the following European bodies: ERTRAC (DAF, TNO, TU's), EARTO (TNO), EUCAR (DAF), EGVIA (DAF, TNO), EARPA (TNO, TU/e), ERTICO (TNO, Technolution, TomTom, NXP, Imtech, Vialis).

The main automotive related topics are:

- 'Smart mobility' and the increasing interest of ITS for traffic flow, GHG reduction and traffic safety
- Electrification of vehicle propulsion and future energy carriers for transportation combined with innovation in combustion engines
- Increasing interest of ICT for a networked transportation system and vehicle control
- New themes like urban mobility and mobility for an ageing community

From 2021 onwards, there will be the follow up Framework Programme Horizon Europe.

2) EUROSTARS

Eurostars supports international innovative projects led by research and development- performing small- and medium-sized enterprises (R&D-performing SMEs). With its bottom-up approach, Eurostars supports the development of rapidly marketable innovative products, processes and services that help improve the daily lives of people around the world. Eurostars has been carefully developed to meet the specific needs of SMEs. It is an ideal first step in international cooperation, enabling small businesses to combine and share expertise and benefit from working beyond national borders. Eurostars is a joint program between EUREKA and the European Commission, co-funded from the national budgets of 36 Eurostars Participating States and Partner Countries and by the European Union through Horizon 2020. In the 2014-2020 period it has a total public budget of €1.14 billion.

3) INTERREG

INTERREG is a European Commission initiative financed by the ERDF (European Regional Development Fund). The aim of this programme is to strengthen economic and social cohesion in the European Union through cross-border, transnational and interregional cooperation. Especially for SME's the GCS Cross border cluster stimulation programme offers opportunities for financial support in collaborations across the borders of The Netherlands, Germany and Belgium. AutomotiveNL is involved in several Interreg projects.

SME Activities Due to limited financial means for SME's, an additional programme will be needed especially for this category of companies. AutomotiveNL is aiming to bundle the innovation forces of SME's around the topics of the programme lines into Theme- Clusters. Furthermore, AutomotiveNL will offer individual management support for incubators with the aim to lower the extremely high entrance barriers in the automotive sector for new entrepreneurial initiatives. Finally, advice and support for SME's is required with respect to project finances ((inter)national funding and subordinated loans). Financial support of SME's will focus on regional (Provinces), (TKI, Innovation Loan) and international (SME program Horizon 2020 and Eurostars)

4) PIB (PARTNERS OF INTERNATIONAL BUSINESS)

One of the typical internationalization SME activities is the Partners of International Business Program (PIB). PIB is a structured, long-term approach in which promising Dutch clusters of organisations are facilitated in international trade and cooperation. PIB offers the opportunity to work with the Dutch government, including its local representatives abroad, to create market access and promote trade. Programmes can be developed in 68 of the countries where the Dutch government is represented by a network of diplomatic missions (in the form of an embassy, Consulate General or Netherlands. At this moment there are several PIB consortia. Partners for International Business (PIB) is a public– private partnership laid down in an agreement detailing the goals, results, and activities to be achieved established by various public and private parties. These goals, results and activities are integrated in the agreement in the form of an action plan that applies for the duration of the programme. A PIB France with twenty participants just started. The reason for this is that only 4% of our exports goes to France where as 44% goes to Germany (See Figure 24). As such intensified relationships with French partners are pursued. Depending upon the Brexit and market, in/export regulations the UK could be a next target country.
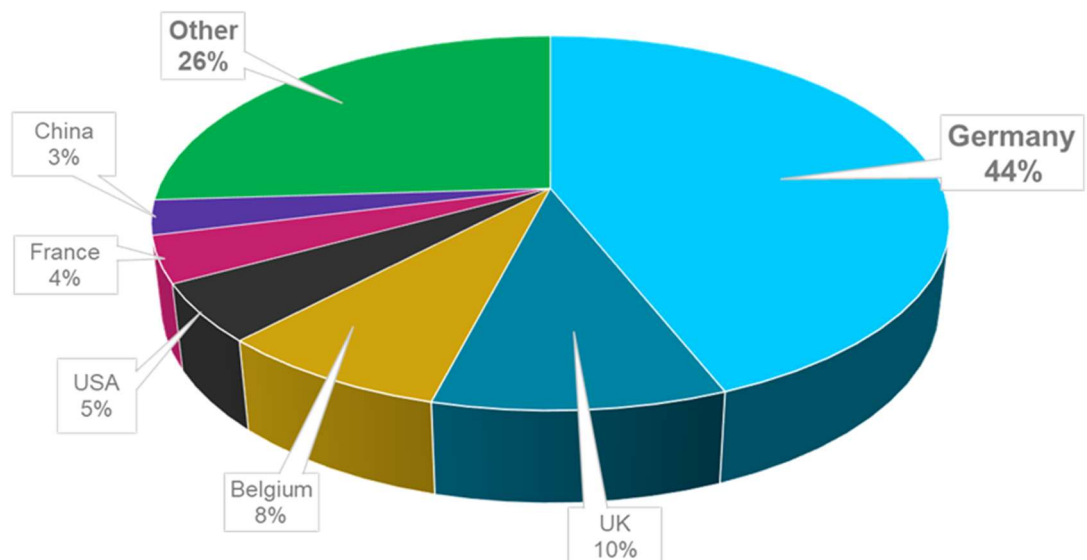

Figure 24. Dutch Export in percentage per Country

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