AUTOMOTIVE ROADMAP 2025 – 2035

RAI AUTOMOTIVE INDUSTRY NL

2025 RAI AUTOMOTIVE INDUSTRY NL

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Foreword

We are proud to present the new HTSM roadmap of RAI Automotive Industry NL. The automotive industry is a vital sector for the Netherlands, generating more than 30 billion euros in annual revenue and providing over 55.000 jobs. This gives the Dutch industry a significant position within the global - and especially the European - automotive value chain. Our sector has long been accustomed to operating in a rapidly changing environment, where globalisation and time-to-market are essential for success.

At the same time, we are facing a global landscape marked by multiple emerging threats. Today's geopolitical tensions create more uncertainty than ever: a war on the European continent, clearly defined yet challenging climate targets, scarcity of raw materials and components, rising import tariffs, and increasing pressure on Europe's automotive industry from major power blocs such as the United States and China. Political uncertainty within the Netherlands further threatens our national earning capacity in this sector. In short, the Dutch and European automotive industries are undergoing one of the most profound transitions in decades, and swift action on all fronts is essential.

Climate objectives require the industry to realise significant CO_2 reductions. The path toward sustainability has been set, and there is no turning back. Whether through battery-electric solutions, hydrogen, or other energy carriers, the automotive industry embraces these developments and delivers the technologies needed to move forward.

The Netherlands plays a key role as a producer of trucks and semiconductors, among other technologies. Our industry is also strong in materials innovation and digitalisation. There are promising opportunities - particularly if we dare to collaborate across sectors, for example with the aviation and maritime industries. Sustainability is central to all of these developments.

At the same time, this is an industry that has always recognised opportunities and fostered entrepreneurship. It is essential, however, that we continue to do so within a fair and competitive landscape. Innovation is the driving force behind strengthening our economic value. Regulation can support this, but it can also hinder progress. Here lies an important responsibility for us as RAI Automotive Industry NL, part of RAI Association, to use our influence both nationally and in Europe with the ultimate goal of keeping mobility accessible and attainable for everyone.

I would like to sincerely thank all individuals and companies who contributed to the development of this new roadmap, and I especially wish to compliment them on the result. It provides a clear and timely overview of the automotive industry within today's landscape. I wish you an inspiring read.

Pim Grol
Managing Director, RAI Automotive Industry NL

Summary

The **Automotive Roadmap 2025-2035** marks a defining moment in the transformation of the Dutch and European mobility sectors. Developed as the successor to the HTSM Automotive Roadmap 2020–2030, this new edition responds to urgent shifts in climate policy, global supply chains, digital disruption, and geopolitical uncertainty. At the heart of the roadmap lie two key pillars: **sustainability and digitalisation**. Both representing important needs for new technology and innovation. This roadmap touches on the technologies and innovations relevant for the Dutch Automotive industry and the main drivers behind them. Compared to the prior roadmap, priorities of the industry are more explicitly defined and primarily defined in the “Acceleration Agenda”. This roadmap can be seen as an update on the important drivers and technologies the industry is facing and working on.

Mario Draghi, former European Central Bank President, shows that there are threats and opportunities in his report entitled: The future of European competitiveness[1]. The independence and competitiveness are interlinked and at stake. At the same time, pressure from societal drivers such as climate change, clean air, accessible mobility and elimination of traffic fatalities is increasing. Simultaneously, the European green deal to transform the EU into a modern ‘resource efficient and competitive economy, plays its role’. The ’ Choose Europe’ movement contributes to this[2]. The aim is to create the conditions to attract talented scientists, researchers, academics and highly skilled professionals to Europe. This will affect the technologies that we need to have in-house and deliver to the automotive industry.

The automotive sector is no longer just about vehicles; it is about systems. Vehicles are becoming increasingly electric, digital, connected, and intelligent. Traditional powertrains are giving way to electric drivetrains, internal combustion engines (ICEs) are being replaced or supplemented by zero-emission alternatives, and mechanical systems are now controlled by software and also human control and supervision is replaced by software. This convergence means that the industry must adapt rapidly, building new ecosystems around energy infrastructure, data platforms, and circular supply chains beyond traditional borders (cross sectoral).

The roadmap acknowledges the critical role of the automotive industry in both the Dutch and European economies. In Europe, the sector supports 13.8 million jobs and accounts for 8% of industrial value added. In the Netherlands alone, it employs approximately 55,000 people, with an annual turnover of €35 to €40 billion of which 85% is export. The Netherlands holds a strong position in heavy-duty truck production and high-tech system components. However, this position is being challenged. Chinese OEMs are gaining ground, labour shortages persist, and software-driven disruption is shifting control away from traditional players.

To navigate these changes, the roadmap identifies a range of economic and societal drivers. Strategically, the Netherlands and Europe must reduce their dependence on external suppliers of critical raw materials and technologies. Electrification, automation, and AI present vast opportunities, but they also require rapid upskilling and large-scale investments. Labour shortages, particularly among truck drivers, are accelerating interest in self-driving vehicles. Meanwhile, new mobility models, such as shared fleets and Mobility-as-a-Service (MaaS), are reducing the need for private car ownership and changing the way mobility is consumed.

Societal drivers are equally important. Climate change, clean air, and urban liveability are pushing cities and governments towards zero-emission transport. The European Union has committed to a 55% reduction in greenhouse gas emissions (37% solely for mobility) by 2030 and aims for all new passenger car vehicle sales to be zero-emission by 2035 (a slightly milder target line applies for HD-Trucks). The Netherlands supports these goals and are working towards local zero-emission zones and clean city logistics. These ambitions put enormous pressure on the automotive ecosystem to innovate rapidly and scale sustainable solutions.

Battery technology lies at the core of this transformation. Innovations such as solid-state batteries and sodium-ion cells promise to improve energy density, safety, and cost. However, scaling battery production raises serious challenges around the supply of lithium, cobalt, and rare earth elements. Europe is responding through the European Battery Alliance and investment in local recycling and reuse systems. Meanwhile, circularity is no longer optional, it is essential. By closing material loops and developing

recycling infrastructure, Europe can reduce its geopolitical vulnerabilities and environmental footprint.

Charging infrastructure is another critical building block. To meet future demand, the Netherlands will need tens of thousands of public and depot chargers by 2030, particularly for heavy-duty vehicles. Yet grid congestion, long permitting processes, and uneven infrastructure rollout threaten to slow progress. The roadmap calls for coordinated planning, smart grids and local energy hubs that combine generation, storage, and demand management.

Hydrogen can play a key complementary role, especially in long-distance freight. This also applies to the use of hydrogen in an ICE[3] instead of diesel. H_2-ICE is an efficient and reliable solution for diesel engines and is much more affordable than a FCEV, especially for heavy-duty trucks traveling long distances. H_2-ICE offers sufficient range for trucks up to 40-50 tons that need to travel throughout Europe where electric vehicles are not an alternative. Furthermore, this concept has potential for other applications, such as off-road vehicles, generators, and shipping. The H_2-ICE could surpass the performance of diesel, primarily due to its high efficiency.

Fuel cell electric vehicles (FCEVs) offer fast refuelling and high range, but cost, efficiency, and infrastructure remain barriers. In the future, FCEVs are likely to coexist with battery-electric vehicles (BEVs), each suited to different transport tasks. In parallel, new fuel types such as eFuels and HVO100 provide low-emission options for sectors and applications where electrification is not yet viable.
Despite the shift to zero-emission technologies, internal combustion engines are not disappearing overnight. The roadmap motivates the importance of improving ICE efficiency and using low-carbon fuels as a transitional strategy. Innovations such as the argon power cycle could significantly improve thermal efficiency and reduce emissions. These are crucial, particularly in freight transport, while zero-emission alternatives scale up.

Digitalisation is transforming how vehicles are designed, built, used, and maintained. Software-Defined Vehicles (SDVs) are replacing legacy systems with centralised computing platforms that control all major functions, from safety to entertainment. Vehicles are becoming rolling data centres that communicate with infrastructure, other vehicles, and users. Connectivity via 5G, 6G and vehicle-to-everything (V2X) communication is enabling real-time decision-making and adaptive routing. Artificial intelligence is enhancing safety, comfort, and efficiency, while cybersecurity has become a core requirement across the vehicle lifecycle.

Autonomous mobility is rapidly becoming a necessity rather than a novelty. In Europe alone, over 700,000 truck driver vacancies are expected by 2028. Autonomous driving technologies promise to address this shortage while improving road safety and logistics efficiency. Congestion also can be reduced if more transport takes place at night. Pilot projects in Europe, the US, and China are already demonstrating fully automated vehicles in controlled environments. However, successful adoption requires robust regulation, digital infrastructure, and a deep understanding of human–machine interaction.

The roadmap stresses the importance of **cross-sector collaboration**. No single sector can solve these challenges by itself. Automotive must work hand-in-hand with energy, ICT, logistics, maritime and aviation sectors to create shared infrastructure, harmonised standards, and interoperable platforms. Technologies developed in one domain such as hydrogen tanks, battery diagnostics, or autonomous navigation can often be applied across multiple sectors. The Dutch HTSM (High Tech Systems and Materials) top sector is coordinating many of these cross-domain innovation efforts.

Manufacturing must also evolve. The Dutch automotive sector is moving towards **smart, circular, and adaptive factories**. Digital twins, IoT sensors, additive manufacturing, and AI-driven quality control are replacing traditional systems. These smart factories will support faster product cycles, real-time monitoring, and highly flexible production lines. Materials innovation such as lightweight composites, recycled plastics, and bio-based alternatives will be essential to meeting both climate targets and customer demands.

The **Automotive Roadmap** is operationalised through the **Acceleration Agenda**, which outlines five national priority areas: charging infrastructure, battery systems and reuse, hydrogen solutions, digitalisation and automation and circular access to critical materials. These so-called “impulse trajectories” aim to accelerate the path from innovation to market and ensure the Dutch automotive ecosystem remains globally competitive.

In conclusion, the **Automotive Roadmap** presents both a strategy and a call to action. It reflects a vision of a cleaner, smarter and societal accepted mobility system powered by collaboration, technology, and shared ambition. To succeed, industry, government, research institutions, and civil society must jointly act now. Only then, the Netherlands and Europe lead the global transition towards sustainable and digital mobility.

1 Introduction

This is the Automotive Roadmap 2025-2035, the successor of the HTSM[4] Automotive 2020-2030 roadmap[5].

This roadmap is written more from the perspective of the industry than before. The reason is that there have been major geopolitical changes on the global stage recently. The USA is more or less retreating into its own shell, while China is undergoing a significant expansion drive, not only towards other Asian countries, but also towards Europe. Therefore also the Netherlands, must leverage its own innovative strength to reduce its dependence on other states.

Mario Draghi, former European Central Bank President, shows that there are threats and opportunities in his report entitled: The future of European competitiveness[6]. The independence and competitiveness are interlinked and at stake. At the same time, pressure from societal drivers such as climate change, clean air, accessible mobility and elimination of traffic fatalities is increasing. Simultaneously, the European green deal to transform the EU into a modern ‘resource efficient and competitive economy, plays its role. The ’ Choose Europe’ movement contributes to this. The aim is to create the conditions to attract talented scientists, researchers, academics and highly skilled professionals to Europe. This will affect the technologies that we need to have in-house and deliver to the automotive industry.

The European Union has committed to a 55% reduction in greenhouse gas emissions (37% solely for mobility) by 2030 and aims for all new passenger car vehicle sales to be electro-mobility by 2035.

The automotive industry has traditionally been one of Europe’s industrial engines. Nevertheless, this industry is undergoing rapid, profound transformation with a shift in demand to third markets, towards green mobility and ‘software-defined vehicles’. As a result, the EU’s traditional leadership in the automotive industry has eroded. (The automotive supply chain in the EU is currently suffering competitive gaps, both concerning cost and technology). The shift in vehicle production is very noticeable. The global market share of car sales from China has risen from 4% to 32% between 2000 and 2022 (See figure 1).

This roadmap focuses on two overarching themes: sustainability and digitalisation. Circularity, material application, and materials are all integrated in sustainability. (Chapter 6). Since the vital importance for an industry that a product is still also very physical’ the subject of material and material handling is discussed in a separate chapter (9).

The roadmap touches on the technologies and innovations relevant for the Dutch Automotive industry and the main drivers behind them. Compared to the prior roadmap,

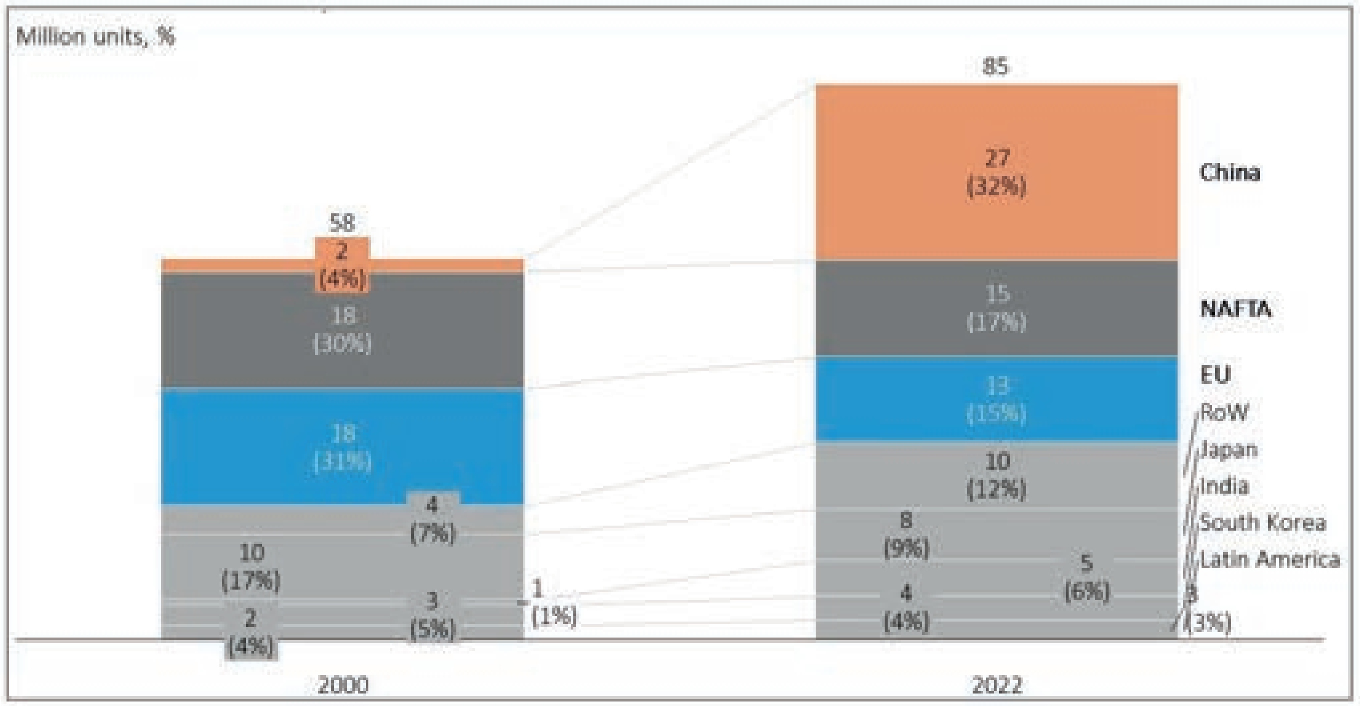

Figure 1: Global car sales 2000 and 2022[7]

priorities of the companies in Dutch industry, as also defined in the recently published “Acceleration Agenda”, are starting point for this document. The Acceleration Agenda[8], emphasises short-term market opportunities and government policy to seize transition opportunities and improve the industry’s position; both are often based on innovation. The “Acceleration Agenda” concentrates on those subjects where several companies are cooperating, also together with partners from the knowledge infrastructure on shared priorities. In all cases, it concerns important and long lasting efforts where involvement of other industries (cross-sectoral) and government is of essential importance.

The roadmap does not discuss how individual companies define their priorities. It rather describes the economical, societal and technological landscape the industry is facing, in which these priorities were set and have to be brought further. The document can serve as an update on the important drivers and technologies the industry is facing and is working on.

The Roadmap highlights the technologies that enable these and upcoming innovations. This involves not only very short-term and short-term priorities, but also long-term continuity and distinguishing technologies. Both short term and long-term continuity are of vital importance for a productive innovation ecosystem.

At the same time, technological challenges lie ahead in the areas of digitalisation and sustainability, against the backdrop of emerging technologies, including Artificial Intelligence, but also those related to rare metals. This roadmap also makes it much clearer that cross-sectoral collaboration is and remains crucial, including with other modalities (shipping and aviation), but also with the nine key technologies and the top sectors: Logistics, ICT, and Energy. Last but not least; this roadmap explicitly reflects various European roadmaps.

With this document, the Dutch automotive industry wants to create clarity on its priorities and commitment in addition to the Acceleration Agenda and sketch the present technology landscape. The primary audience for this document includes Automotive Industrial stakeholders (OEM[9] and TIER[10] suppliers), governmental stakeholders, research and educational institutes and cross-sectoral stakeholders. Cooperation between all these stakeholders is a key prerequisite as argued in the Acceleration Agenda. This roadmap is an invitation for cooperation.

This roadmap document is organized as follows:
Chapter 1 describes the background to this roadmap as successor to the 2020-2030 roadmap. Chapter 2 describes the transformation of the Automotive sector. Chapter 3 and 4 describe the facts and figures of the European Automotive sector and for the Netherlands. Chapter 5 describes the global automotive industry that is undergoing a tremendous amount of changes at an unprecedented pace. Cross-sectoral links to other sectors are also being established. Different sectors can strengthen each other through technological approaches. Chapter 6 describes the sustainability solutions and in Chapter 7 the ongoing digitalisation of the automotive mobility sector is written. Chapter 8 describes the necessity of cross-sectoral collaboration. Chapter 9 describes the interdependence of circularity, materials and manufacturing priorities for the Dutch Automotive sector both in the short – and the long term. And finally in Chapter 10, the priorities of the Dutch automotive industry are discussed.

2 Transformation of the automotive sector

The automotive industry has traditionally been one of Europe’s industrial engines. Nevertheless, the industry is undergoing rapid, profound transformation with a shift in demand to third markets, towards green mobility and ‘software-defined cars’. The automotive supply chain in the EU is currently suffering competitive gaps, both concerning cost and technology[11]. Its transformation combines an evolution in the industry’s geographical footprint and the formation and convergence of multiple value chains (including the EV, digital, mobility and circular-economy value chains) which differ substantially from the production and the lifecycle of traditional internal combustion engine (ICE) vehicles.

The shift in demand towards third markets is in line with the shift in the geography of global economic activity and the growth in per-capita income in emerging economies. The rise of electric vehicles means a far-reaching change in the technology, production processes, skills demand and inputs needed by car manufacturers and supplier networks.

Major industry reorientation is needed, including the reskilling of workers and leaner supplier networks, as well as the development of charging infrastructure. The integration with the digital value chain shifts the automotive from a traditionally ‘hardware-based’ mechanics industry to a situation that the value of vehicles is increasingly located in software. The integration with the mobility value chain includes energy services: the availability of charging and refuelling infrastructure for low-emission cars and trucks is The automotive industry has traditionally been one of Europe’s industrial engines. Nevertheless, the industry is undergoing rapid, profound transformation with a shift in demand to third markets, towards green mobility and ‘software-defined cars’. The automotive supply chain in the EU is currently suffering competitive gaps, both concerning cost and technology[11]. Its transformation combines an evolution in the industry’s geographical footprint and the formation and convergence of multiple value chains (including the EV, digital, mobility and circular-economy value chains) which differ substantially from the production and the lifecycle of traditional internal combustion engine (ICE) vehicles.

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The introduction of zero emission technologies will need to ramp-up as quickly as possible, infrastructure bottlenecks are expected to constrain progress until 203012. This was illustrated in a meta study[13], comparing the cost of the energy transition in a selection of roadmaps. In addition, both reports investigated potential resources such as solar and wind energy and critical component scarcity, as the demand for critical minerals for clean electricity supply and electrification technologies both will increase drastically. Other studies highlighted that even if resource availability would not be a concern, scaling-up mineral supplies fast enough might still remain a challenge[14].

In short, most agree that the powertrain of the future vehicles will be entirely electric. However, there’s a catch. It’s important to remember that the enabling conditions such as, digital infrastructure, financial incentives, R&D support

and simplification and harmonization of regulation and other enabling conditions (see table 4), shouldn't be an obstacle. This also applies to technology trends, such as AI.

Digitalisation has become an indispensable driver for the modernisation of the entire system, making it seamless and more efficient. Europe also needs to use digitalisation and automation to further increase the levels of safety, security, reliability, and comfort, thereby maintaining the EU's leadership in transport equipment manufacturing and services and improving her global competitiveness through efficient and resilient logistics chains.
Artificial Intelligence plays a major role in future services, and digital value chains in connected and automated driving as well as intelligent mobility services. Digital technology evolved from a general enabler to a key technology in Automotive. The importance of artificial intelligence is following a similar path or even faster. With the foundation in place, artificial intelligence moved to the forefront. Vehicles are no longer just connected; they were learning, predicting, and adapting.

Driver monitoring systems could detect fatigue or distraction and recommend rest breaks. Personal assistants evolved from voice commands to full generative interfaces, customizing user experiences based on preferences, habits, and even moods. Roadside information, including roadside sensor data can extend the limit of environmental perception of automated vehicles.

AI developments in the digital domain can have major impact on the use of vehicles and the applied technology. The ICT infrastructure (5G, 6G) including business models, will end up in new challenges and opportunities for all stakeholders of road transport.

3 EU Automotive: facts and figures

The automotive industry is a structurally important segment of the EU's economy. It is a major employer, providing directly and indirectly (downstream industry) jobs for 13.8 million Europeans, representing 6.1% of total EU employment. 2.6 million people work directly in the manufacturing of motor vehicles, which is 8.5% of the EU's manufacturing employment. The automotive industry contributes 8% of European manufacturing value added, and it has a EUR 117 billion surplus in (extra-EU) trade, which corresponds to approximately one-fifth of the value of automotive production[15]. The EU remains a net exporter of vehicles both in terms of the value of net trade and the number of vehicles, and it is also a net exporter of car parts. Around 75-80% of the value of vehicles traditionally comes from car part suppliers[16]. The road transport sector supports the economic position of Europe worldwide. Additionally, it provides an important contribution to the budget of public authorities across the EU with over €390 billion of government revenues. In terms of research investment, it is the highest spending sector in Europe with almost €60 billion invested annually in R&D[17].

4 NL Automotive: facts and figures

The Dutch automotive sector is a major industrial activity supported by top-level knowledge institutions. The Netherlands offers space for a total of 55,000 employees within the automotive manufacturing industry, who together generate a turnover of 35-40 billion[18], of which more than 85% is exported. DAF achieved a solid market share of 14.4 percent in the heavy-duty truck segment in Europe, which amounted to 316,000 vehicles in 2024. In the United Kingdom (27.1%) and the Netherlands (28.9%), DAF remained the undisputed market leader. Moreover, in Germany and France, Europe's two largest truck markets, DAF was the largest import brand for heavy-duty tractors. In the medium-duty truck segment (50,900 units in 2024), DAF held a market share of 9.5%, leading both in the United Kingdom and the Netherlands[19]. Scania produces 44.000 trucks in Zwolle (NL)[20]. Also in the public transport and special vehicles sector, several Dutch suppliers provide high-quality components and systems to the automotive industry (often also to the very large passenger car market), thus accounting for approximately half of the automotive turnover in the Netherlands.

The transition from diesel to zero-emission and the increasing importance of software in and around the vehicle are also creating market opportunities for adjacent market segments (charging infrastructure, hydrogen infrastructure, and ICT). This large market share in HD, amongst other areas, is rapidly getting under pressure. One of the most important, now clearly visible, factors in this situation is the transition to zero-emission technology (currently almost every one drives diesel). Less visible, but irreversibly on its way, is the increasing development of digitalisation and automation, including at vehicle level. These transitions are reshuffling the cards. The dominance of software and data (and the associated tech companies from outside Europe) and the availability and reuse of raw materials will also play an increasingly important role. These developments far exceed the scope of individual companies and even an entire sector but are nevertheless of great importance for their future and/or location.

5 Drivers

As stated in Chapter 2, the global automotive industry is undergoing a tremendous amount of changes at an unprecedented pace[21]. In the midst of a major disruption, there are both challenges and opportunities. The shifting balance of power, spread of new technology and reshaping of supply chains means that automotive players of all types – OEMs and suppliers, incumbents and new market entrants – need to prepare themselves for the marathon ahead[22]. Also the ever-growing role of AI cannot be ignored. Drivers and challenges can be classified into economic and social factors that are discussed in the following paragraphs.

5.1 Economical drivers

5.1.1 Strategic Independency

Strategic independency in the automotive sector, especially regarding rare earth materials and critical metals, offers several vital benefits, particularly when looking at the geopolitical dynamics amongst China, the United States, and Europe. Rare earth elements (REEs) like neodymium, dysprosium, and terbium are crucial for EV motors, batteries, and advanced electronics. In addition to these elements, the level of energy costs is important for competitive manufacturing. As the oil crisis of 1973 and 1979 proved; strategic independence from fossil fuel import is extremely important for the EU as a continent and is also driving the energy transition. Battery (cell) technology is the other important dependency while going all electric. Another example is the shortage of permanent magnets; this threatens entire industries.

5.1.2 Shortage of Drivers

There is a permanent and increasing shortage of truck drivers[23]. This is partly due to the aging population and the increasing demand to transport services. There are shortages across the entire logistics sector. These shortages will not be resolved in the coming years, which is detrimental to economic growth. One solution to the driver shortage is the self-driving truck.

5.1.3 Automation

The logistics sector boasts significance advantages, namely fewer trips, and productivity gains (less personnel costs). Also in the public sector transport and the taxi business, automation is expected to play an important role in the future. Furthermore; sparsely populated areas are better served. This also reduces environmental impact due to more optimized route planning.

5.1.4 Shared Mobility

The economic benefit of shared mobility is that there is no need for full vehicle ownership (fuel, insurance, maintenance). Besides that it's possible to reach higher utilization rates. A single shared vehicle can replace multiple privately owned or underused vehicles. Professionally managed fleets of shared vehicles will reduce the cost of mobility by a significant amount through more efficient use of expensive mobile assets.

5.1.5 Continuously updated

The range of models will be updated yearly, or even faster to integrate the latest hardware and software developments and react to changing requirements of shared fleet buyers. Many services, from a final OEM manufacturer, are provided directly to the end customer. The distance to the end consumer is therefore shrinking.

5.1.6 Trade policy

Trade policy is a profound influence on the automotive sector's strategic independence, especially if rare earth materials, cross-sectoral innovation, automation and robotization are considered. Next to the above mentioned issues, the access to human capital is very important for creating the innovations of the future. The Choose Europe movement is especially initiated for this [24].

5.1.7 Cross sectoral Collaboration

The interdependence between sectors is playing an increasingly important role in social and economic developments. The very high speed at which sectors must act due to transitions, both socially (impact of CO^2 targets) and economically (impact of digitalisation), makes these interdependencies increasingly decisive for the success and progress of innovation and implementation. In the field of innovation, the importance of cross-sectoral projects is increasing (see also Chapter 8).

5.2 Societal drivers

The technological development direction in the automotive sector must lead to a number of social goals, namely:

- Reduction of greenhouse gas emissions
- Zero impact pollutant emissions
- Zero emission zones
- Transition towards sustainable energy carriers
- Traffic safety
- Accessible, inclusive mobility and accessible cities and regions

5.2.1 Reduction of greenhouse gas emissions

Europe has pledged to achieve net-zero greenhouse gas emissions by 2050, with interim targets: –55% by 2030 vs.

1990 levels, making transport, responsible for ~25–30% of CO2 emissions; a critical sector. The Netherlands aim for a zero-emission vehicle (ZEV) sales share of 100% by 2035. The transition to emissions-free mobility will become a global requirement. Electricity used to charge vehicles will increasingly come from renewable sources to ensure carbon dioxide neutral mobility. The heavy duty vehicle industry has CO2 target for trucks >16 tons of -15% for 2025-2029, -43% for 2030-2034, -64% for 2035-2039 and -90% as of 2040. These targets are relative to reference year 2019. Hydrogen and other solutions could play a role, next to battery electrification, as well.

5.2.2 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 (NOx), 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. 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 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 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 an 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[25].

5.2.3 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 set out key actions to support the European Green Deal[26], 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 equipment and mobile machinery is a target, partly driven by nitrogen emission limits in the Netherlands.

5.2.4 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, 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[27].

5.2.5 Traffic safety

The accident statistics over the past 10 years show that further reducing accidents is becoming more challenging. A more systemic approach covering vehicles, infrastructure and road users is needed to achieve Vision Zero[28]. The EU's ambition is to achieve zero road deaths by 2050 (Vision Zero). However, progress is levelling off. There was even an increase in the number of road deaths in 2022. There were 745 deaths, while the number in 2021, 582 was. New forms of mobility such as electric bicycles have contributed significantly to this.

Vehicle manufacturers see an important contribution from digitalisation[29]. Consistent methods and assessment tools are required to fully understand the safety impact of further digitalisation of road transport and derive safety requirements.

5.2.6 Accessible, and societal accepted mobility and accessible cities and regions

The liveability of urban environments (where 75% of Europeans live and 85% of GDP is realised) has become a specific priority for many European cities as well as for the EC. Accessibility, the increasing share of vulnerable road users and the importance of integral, but also flexible (tailor-made) and on-demand solutions are important[30].

Changing attitudes among younger generations, greater urban densification, increased ageing population and digital-first lifestyles are moving demand from vehicle ownership to shared mobility[31], on demand car sharing, and Mobility as a Service (MaaS). Meanwhile, last mile logistics are rapidly electrifying and consolidating around micro fulfilment centres. In addition, professionally managed fleets of shared vehicles will reduce the cost of mobility by a significant amount through more efficient use of expensive mobile assets.

6 Sustainability

Sustainability in the automotive industry refers to the efforts made by manufacturers and stakeholders to reduce environmental impact, improve resource efficiency without compromising economic viability. A shift from internal combustion engines to electric and hybrid vehicles is the most obvious step. Circularity directly contributes to sustainability. By extending the life of products and minimizing waste, pressure on natural resources is reduced, pollution is limited, and the ecological footprint is minimized. Circularity is based on an economic model in which raw materials, resources, and products are used, reused, and recycled for as long as possible. In a circular economy, there is no such thing as «waste» in the traditional sense; everything is seen as a raw material for something new. Sustainability and circularity also contributes to independency (from fossil fuel and other imports).

Besides the sustainable focus, circularity has also become more important in recent years for geopolitical reasons (see also paragraph 6.5). Circularity in production and recycling raw materials is being treated in Chapter 9.

Until twenty years ago, nearly all investments in powertrain innovations were released on the combustion engine, making it untouchable, which encourages path dependency[32]; the current product range is being further developed, making it increasingly more economical and less polluting. This is then a case of incremental changes. And that is the path that has been taken over the past hundred years. However, the problems are now so alarming due to climate change and (focus on) pollution that incremental innovations are no longer sufficient. Radical (also called revolutionary) innovations can only solve these problems, although often they are expensive to develop. It is also risky for a car manufacturer to bring these to the market quickly, due to the high costs that this entails due to an inefficient manufacturing process, but also due to the collaboration with suppliers that has not yet been sufficiently crystallized. Above all, it is uncertain how the market will move due to the application of new technologies. It doesn't happen by itself: industry and governments must work closely together to be able to realize and implement radical innovations. Cooperation between government and industry for introducing and making transitions marketable is a necessity. The future zero emissions vehicle solutions are rapidly emerging. However, large-scale adoption of sustainable mobility solutions depends on user experience and meeting customers' expectations. Advancing zero-emission technologies for vehicles (BEV[33], FCEV[34]) is crucial to increase performance and sustainability.

6.1 Battery

There are thousands of different configurations for batteries to be made, each focused on certain specific properties on different parameters. There is not one holy grail, because some are promising technologies in battery development that require a long development time, such as solid-state batteries; a battery that consists of a solid electrolyte. This is in contrast to a lithium-ion battery or a lithium-ion polymer battery, which contain liquid or polymer electrolytes. Lithium extraction has faced scrutiny for its environmental impact, but amongst others, sodium is abundant and easier to source. Thus there is also a focus on Sodium-ion batteries as the future prevalent battery technology. It's a potential successor/replacement for Li-ion, but innovation and market stimulation is needed before it can be widely adopted[35]. New batteries with higher energy- and power-density (figure 2) are being developed in rapid succession, even though many do not get beyond the R&D phase. While electric vehicles (EVs) may face a temporary growth rate slowdown, they are projected to surpass the internal combustion engine (ICE) vehicles by 2036 according to Forbes[36]. This shift will mark a significant turning point in the automotive industry, driven by advancements in battery technology, reducing battery prices below $80 per kWh, and increasing battery life cycles. Despite that, European manufacturers are still dependant of China for both CRM and battery cell production technology. This will affect how we have to deal with that in the coming years.

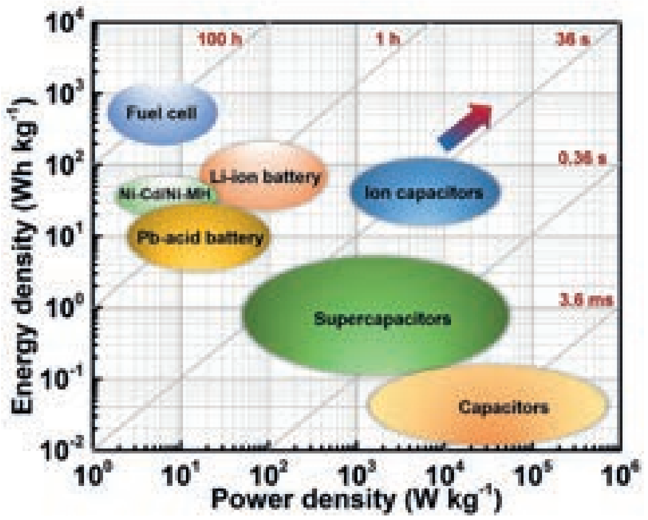


Figure 2: The comparison of energy density and power density for different energy storage devices[37]

New solutions are also needed because of the growing demand for Lithium. A promising technology is the Sodium battery. Sodium-ion batteries offer a safer and more sustainable alternative to traditional Lithium-ion technology.

The main drivers of rising battery demand are electric vehicles, stationary energy storage systems and portable electronics. Lithium could become the limiting factor in electrification, as demand is growing faster than supply. In a market forecast, the German Mineral Resources Agency (DERA) concludes that 'there could be massive supply bottlenecks in 2030'. To stimulate groundbreaking innovations and prevent the problem of shortage of rare metals in the future, Europe is committed to a European Battery Alliance, vertical battery value chain integration, and a renewed Industrial strategy[38].

6.2 Charging

EV[39] charging shall have an important impact on the local energy grids. The advanced planning of network upgrades and reinforcement, tuned with higher voltage levels, will become crucial. The permitting and construction of new substations and HV lines usually takes a long time, which is incompatible with the fast needs of transport electrification[40]. Investments in distribution grids will need to increase on top of the historic efforts[41], and must grow threefold this decade. The IEA[42] indicates that worldwide 80 million kms of power lines will need to be added or upgraded by 2040, in less than twenty years[43].

In order to ensure an effective and sustainable transition towards decarbonized low-emission transport sector by 2050, all technological options and fuels (including electricity), need to be allowed to compete for reducing emissions in the different transport modes.

Energy carriers will seamlessly merge in the future. Hydrogen becomes electricity and vice versa, depending on supply and demand, with scale being important for automotive. Distributed generation and storage is a trend, depending on local conditions and important to overcome the problems caused by (green) power supply shortage and grid congestion. Much of the technology, range, scale and reliability needed for local energy hubs come close to those applied in automotive industry.

6.3 Hydrogen

Sufficient availability of hydrogen at a competitive price is still an issue. To date (and still is) the hydrogen truck (FCEV) is inferior in terms of Total Cost of Ownership (TCO) compared to a diesel truck or a BEV truck. Only where the BEV truck has too many disadvantages in terms of range for specific journeys, the hydrogen truck could be interesting.

The competition between FCEV and BEV in terms of TCO, especially for longer distance journeys, is intensifying. This means that there is a chance that both technologies can coexist for the time being, which justifies the importance of investing in both options. This also applies to the use of hydrogen in an ICE instead of diesel. This technically is a relatively simple solution. Finally, fuel cell long-haul trucks can reach TCO parity with their diesel counterparts by 2030 in Europe if the at-the-pump green hydrogen fuel price is around 4 € / kg[44]. Despite this, a BEV truck is still much more attractive in terms of cost price than an FCEV truck, especially for shorter distances. If sufficient hydrogen (white[45] or green[46]) becomes available at a low price, the issue of lower efficiency is also less important. In addition, many investments are being made in new fuel cells and electrolysers, which will significantly reduce energy losses.

Many investments are being made in new fuel cells and electrolysers, which will result in much lower energy losses.. This also applies to the use of hydrogen in an ICE[47] instead of diesel. H^2-ICE is an efficient and reliable solution for diesel engines and is much more affordable than a FCEV, especially for heavy-duty trucks traveling long distances. H^2-ICE offers sufficient range for trucks up to 40-50 tons that need to travel throughout Europe where electric vehicles are not an alternative. Furthermore, this concept has potential for other applications, such as off-road vehicles, generators, and shipping. The H^2-ICE could surpass the performance of diesel, primarily due to its high efficiency.

6.4 ICE

ICE research needs to focus on areas such as improved fundamental engine thermodynamics efficiency, (where applicable) as well as improved HD-ICE operational cycle efficiency ICE research needs to focus on areas such as improved fundamental engine thermodynamics efficiency, engine downspeeding and/or engine downsizing solutions (where applicable) as well as improved HD-ICE operational cycle efficiency in an increased diversity of transport missions. Combustion process improvements (cylinder pressure, chamber shape, improved heat rejection, fuel injection, etc.) will also be needed and can still deliver potential efficiency improvements of about 3-5%[48]. Stopping the development of ICE is not on the agenda for the time being. As an example, Eindhoven University of Technology (TU/e) is engaged in a Research project, named argon power cycle. The focus of this project is on a revolutionary power cycle that converts energy from renewable fuels into power, with substantially enhanced efficiency by using argon as working fluid[49].

The efficiency of a thermal power cycle is limited by the specific heat ratio of its working fluid. By using argon instead of air, the cycle efficiency can be increased by about 25% reaching values above 80%. A new internal combustion cycle that circulates argon will be explored in this project. Such a closed-loop argon power cycle (APC) would most conveniently burn hydrogen and oxygen, leading to an exhaust stream that is emissions-free and effectively contains only water and argon, which allows for easy separation by condensation.

If the price of H^2 drops significantly, there will also be opportunities for the use of eFuels. eFuels, or electric fuels or synthetic fuels, are an alternative to fossil fuels that are produced using renewable energy sources such as wind and solar energy. They are made by combining hydrogen with CO^2, which is extracted from the air or from other sources. These synthetic fuels can be used in combustion engines, without major technical adjustments. And there is also an opportunity to quickly make (possible existing) vehicle fleets more sustainable. It offers the same possibilities as driving on diesel fuels: fast refueling and a large range.

An alternative is HVO100, a synthetic diesel fuel chemically very similar to traditional diesel, but made from renewable resources. It is produced by treating vegetable oils and animal fats with hydrogen. This process results in a clean, high-quality diesel fuel suitable for use in most diesel engines. Using HVO100 can reduce CO^2 emissions by up to 90% compared to traditional diesel.

All in all, short and medium distances by 2030 and beyond may be more fitted for electric batteries and local stationary charging stations, while long-distance may be better equipped with highly efficient ICE powertrains with low emission liquids or gaseous fuels, or alternatively with electrified fuel cell or hybrid solutions. Another option is using dynamic charging along electrified roads[50]. According to TNO the business case and scalability are not that strong.

6.5 Circularity

COVID-era supply chain disruptions, rising energy prices, and conflicts (e.g. Ukraine) have exposed vulnerabilities in import dependence of critical minerals and semiconductors[51]. The geopolitical risk associated with lithium, cobalt and chip sourcing has catalysed a shift towards supply chain resilience. In addition; the European automotive supply industry is experiencing significant disruption due to China's recent export restrictions on rare earth elements and magnets. These restrictions have led to the shutdown of several production lines and plants across Europe, with further impacts expected as inventories deplete[52].

Sustainable mobility requires processes that contribute to a circular economy while reducing waste and the environmental footprint along the value chain. Return facilities (especially for end-of-life EVs) are key for global recycling loops across markets and regions. Establishing closed-loop recycling, especially for critical raw materials (e.g. Li, Ni, Mn, Co, Mg) is a geopolitical necessity. The massive shift to renewable energy and green technologies, needed to meet the obligations under the Paris Agreement, will require an exponential increase in the use of critical raw materials by 2050[53]. Research is needed to identify feasible processes (e.g. separating, sorting and tracing) for polymers, electronics and electronic components as their recycled material contents are crucial in the future[54]. And also especially to develop technologies/components that require less of those critical materials. The industry is increasingly applying circularity in their development - and design processes.

7 Digitalisation

A wave of digital innovations is sweeping across the world, shifting consumer demands, climate goals, and the unstoppable advance of technology[55]. The old paradigm; vehicles defined by hardware, powered by fossil fuels, and repaired in garages, was rapidly giving way to a new world of Software-Defined Vehicles (SDVs), edge-cloud ecosystems, and artificial intelligence (AI). This transformation was not just a technological leap; it was a redefinition of mobility itself. The global automotive value chain is more or less being disrupted by the entry of platform driven competitors, Chinese OEMs targeting export markets and Big Platform firms (Google, Baidu, Amazon, Apple) bringing software and AI capabilities. Approximately ten years ago, it was expected that traditional OEMs would have to transform in to mobility and digital service providers, and no longer, just automotive hardware manufacturers[56].

According to EUCAR[57], digitalisation plays a major role in the research ambitions of the European automotive industry. The era of transport and mobility digitalisation has a significant impact on the design, architecture, and development of vehicles, enabling their further seamless integration into the transport and mobility system and digital environment. This includes a stronger connection with other modalities.

Digitalisation of Road Transport and its technologies will play a vital role in achieving safer, cleaner, smarter and more efficient transport solutions: the goal is to further reduce transport emissions and congestion, while ensuring mobility in particular for the elderly and people with disabilities. Enabling new mobility concepts will shift design and development from driver-centred to mobility-user-centred[58]. Digitalisation can also assure that production processes run more efficiently and more reliable. This requires a cross-sectoral approach, with the government also playing a key role. This involves data and software infrastructures that enable and support automation of the logistics process (physical internet) and the associated vehicles (software-defined vehicle), including safety and security and an innovation-friendly experimental and approval regime Furthermore, an accelerated focus on further (partial) automation and robotization of logistics locally and on transport routes that lend themselves to this will strengthen the Netherlands' economic position as a logistics hub within Europe and provide a significant boost for many companies within and outside the automotive manufacturing industry.

In short, the benefits of digitalisation in the automotive sector are:

- Improved road safety: Supporting the 2050 Vision Zero goals, aimed at reducing road accidents.
- More efficient mobility: Reducing emissions and congestion while improving inclusive mobility, especially for seniors and people with disabilities.
- New mobility concepts: Shifting from a driver-centric to a user-centric approach to mobility.
- Automation and connectivity: Integrating data and automated driving to improve the interaction between vehicles, infrastructure, and other road users.
- Safety and reliability: Developing secure and scalable communication systems within vehicles and between vehicles and infrastructure[59].
- Manufacturing more cost efficient and reliable.

Furthermore an accelerated focus on further (partial) automation and robotization of logistics locally and on transport routes, will strengthen the Netherlands' economic position as a logistics hub within Europe.

Artificial Intelligence plays a major role in future services, and digital value chains in connected and automated driving as well as intelligent mobility services. Digital technology evolved from a general enabler to a key technology in Automotive. The importance of artificial intelligence is following a similar path or even faster. With the foundation in place, artificial intelligence moved to the forefront. Vehicles are no longer just connected; they were learning, predicting, and adapting.

Driver monitoring systems could detect fatigue or distraction and recommend rest breaks. Personal assistants evolved from voice commands to full generative interfaces, customizing user experiences based on preferences, habits, and even moods. Roadside information, including roadside sensor data can extend the limit of environmental perception of automated vehicles (fig 5).

AI developments in the digital domain can have major impact on the use of vehicles and the applied technology. The ICT infrastructure (5G, 6G) including business models, will end up in new challenges and opportunities for all stakeholders of road transport.

Cybersecurity is crucial for the automotive industry, especially as vehicles become increasingly connected and autonomous. To prevent cybercrime from affecting cars and the industry as a whole, manufacturers must adopt a security-by-design approach, embedding cybersecurity into every layer of development. This is in any case a much broader development than just automotive, so it is favourable to develop this in connection with other sectors. Strong encryption, secure authentication methods, and isolated systems for critical functions are essential to reduce vulnerabilities. Over-the-air updates must be protected and regularly deployed to patch potential flaws. Collaboration is key. Automakers, suppliers, and regulators must share threat intelligence and best practices across the industry. Without these measures, the risk of remote hijacking, data theft, or operational disruption grows significantly, potentially endangering lives and undermining trust in modern mobility. Proactive cybersecurity is not optional; it is a fundamental requirement for the safe future of transport.

Strong encryption, secure authentication methods, and isolated systems for critical functions are essential to reduce vulnerabilities. Over-the-air updates must be protected and regularly deployed to patch potential flaws.

In its CCAM[60] roadmap[61] ERTRAC[62] predicts among other things, that by 2050 nearly all vehicles on highways will be able to operate without immediate driver intervention and so give driving time back to the driver, which he or she may use for various purposes including relaxation and increased productivity. In addition, all cars and trucks on all roads have very sophisticated supporting systems installed, including reactions on traffic lights, roundabouts etc. and so contributing significantly to near zero crashes as well as further reducing emissions (e.g. from tires and brakes).

7.1 Connectivity, Data seamless system of systems

As vehicles became more intelligent, their need to connect with their environment is intensified. The roll-out of 5G, 6G, Cellular Vehicle-to-Everything (C-V2X), and ITS-G5 networks across the EU provided the infrastructure necessary for real-time communication. Projects like SmartwayZ.NL[63] became proving grounds for ultra-low-latency systems that connected vehicles to traffic signals, other vehicles, pedestrians, and cloud services. A connected car is a vehicle equipped with internet access and the ability to communicate with other devices, systems, and the internet itself. This connectivity allows for a wide range of features and services, from navigation and entertainment to safety and maintenance.
Digitalisation of road transport technologies and new business models involve producing and communicating huge sets of data. Secure and trustful communication inside the vehicle, between vehicles and other road users, and the infrastructure is essential. For automated driving, current vehicle technologies already provide advanced assistance functions, relying on sensing and data fusion processing enabling 360 degree traffic situational awareness. The automotive domain is rapidly changing in the last years.

OEMs (i.e. the vehicle manufacturers) are facing different challenges; vehicles are evolving into systems of systems. Over the last years vehicles have evolved from disconnected and "blind" systems to systems that are able to sense the surrounding environment and connect with other vehicles, the city, pedestrians, cyclists, etc. Future transportation systems can be seen as a System of Systems (SoS)[64].

This applies two ways: communication between cars or with traffic management infrastructure or between vehicle occupants and the outside world. The car of the future will become a "third place" between home and workplace, combining features of both.

7.2 Software-Defined Vehicles

Traditionally, cars were built to perform mechanical functions such as steering, accelerating, and braking. However, the development of SDV is transforming the automobile industry by incorporating advanced software systems that can control and coordinate various functions of the vehicle, such as infotainment, driver assistance, and connectivity, among others. This has led to the creation of sophisticated and complex electric/electronic (E/E) architectures that can adapt to changing requirements and enable new capabilities in modern vehicles[65].

One of the most transformative shifts in this decade is the migration from traditional Electronic Control Units (ECUs) (of which modern cars had over 100), to centralized domain controllers and zonal architectures. Instead of hundreds of isolated components, SDVs used high-performance computing platforms to orchestrate vehicle functions via shared software platforms As software is taking an increasingly important role in vehicle operation, software-defined vehicles (SDV) enable new features, reshaping future mobility with increased cloud integration. Future vehicles need advanced computing power for many safety, sustainability, and overall efficiency and performance applications[66]. This means that for suppliers deeper in the chain (tier 2 and beyond), their competence in the field of software and model-based system description becomes more important (and that Tier 1 suppliers are increasingly being overlooked). In the most extreme cases (BYD and Telsa), OEMs integrate important parts of their supplychain.

7.3 Automated transport and mobility

Automated driving is a necessity due to the current shortage of truck drivers, which will further increase towards 2030. The International Road Transport Union (IRU) sees that there are already more than 233,000 unfilled vacancies for truck drivers in Europe and expects that there will be more than 745,000 vacancies by 2028[67,68].
The development of vehicles which require no human

intervention, will reduce the use of public mobility platforms and offer individual mobility to new user groups. Autonomous vehicles are no longer a thing of the distant future. Self-driving cars reduce road safety concerns, make mobility more accessible, (and reduce the cost of transportation[69]).

In the US and China[70], experiments with advanced forms of autonomous driving are increasingly underway, and Germany also has an ambitious agenda[71]. The use of robotaxis[72], in several US cities is large-scale and far-reaching in terms of functionality, but still limited in their (physical) application area (ODD: Operational Design Domain). Volkswagen recently announced that it will soon launch robot taxis in Europe and thus appears to have caught up[73]. Fully automated driving is already possible with the help of a remote driver or teledriver (see fig. 3), a human operator who controls a vehicle from a location separate from the vehicle itself, using a remote control interface.

Figure 3: Remote driver[74]

Further advancing technologies will enable vehicle control for longer time periods towards highly automated driving. The vehicles will also leverage connectivity and data sharing in complex traffic environments to extend the operational design domain (ODD) for Automated Driving functions. In the future, a mix of connected, automated and conventional traffic for a long time is expected. Stakeholders work together to ensure the smooth and safe coexistence of all other road users[75].

7.4 Safety

In addition to the significant contribution made by passive safety measures (from seatbelts to airbags), automobile manufacturers see future improvements on the vehicle side primarily in more extensive active safety measures. These currently primarily concern systems (ADAS[76]) assisting the driver with tasks performed (e.g. maintaining a safe distance on the highway). For autonomous vehicles, this encompasses all driving tasks. The knowledge required for developing autonomous vehicles is therefore also highly relevant for ADAS systems and vice versa. Besides the knowledge required to safely develop and implement these supporting or more extensive functions, understanding human behaviour in interaction with these systems is essential. This applies to the vehicle users themselves, but certainly also to other (including vulnerable) road users. Besides the vehicle itself, further improvements to the infrastructure (including digital infrastructure, see, for example, ISAD[77]) are highly relevant, as is the collaboration between road authorities and automobile manufacturers.

As part of its mission to achieve ‘Vision Zero’ (eliminating all traffic fatalities and serious injuries), Euro NCAP has turned its testing and safety performance attention to the HGV (heavy goods vehicle) category for the first time.

Due to their size and weight, HGV crashes are the most severe on European roads. Although trucks account for less than 3% of the traffic fleet in Europe, they are responsible for 15% of accident fatalities. Furthermore, only 11% of casualties in accidents involving HGVs are truck occupants. The remaining 89% are car and van occupants, as well as Vulnerable Road Users[78].

8 Cross sectoral cooperation

The interdependence between sectors is playing an increasingly important role in social and economic developments. The very high speed at which sectors must act due to transitions, both socially (impact of CO^2 targets) and economically (impact of digitalisation), makes these interdependencies increasingly decisive for the success and progress of innovation and implementation. In the field of innovation, the importance of cross-sectoral projects is increasing. For the automotive sector, this means that collaboration within the top sector HTSM will play an increasingly important role, but also with several other sectors. Further on (Chapter 10), the major innovation projects initiated within the Dutch automotive sector are discussed. These all need significant input from other sectors. Technologies involved are for example: high-pressure tanks for hydrogen storage and the optimization of interlocking systems. Also across sector boundaries, for example, charge planning for battery electric vehicles with involvement from the logistics, energy, ICT, and automotive sectors). SDV[79] will enable cross-industry collaboration beyond current limitations, with new partnerships and open ecosystems emerging[80].

Topsector HTSM

The automotive industry is one of the world’s most important industries and a key application area for high-quality technology. In addition to the direct technological efforts made by the sector itself, efforts in most HTSM key areas are also relevant to the «Sustainable Mobility» innovation domain, as well as those in other innovation domains.

Innovation domain	Relevance Automotive application area	Relevance Acceleration agenda
Circular Economy	*****	*****
Sustainable Mobility	= application area	
Energy Materials	*****	*****
Imaging Technologies		
Mechatronics & Optomechatronics		
Optical Systems & Integrated Photonics	*****	*****
Quantum Technologies	in future	
Semiconductor Technologies	*****	*****
Smart Industry	*****	*****
Systems Engineering	*****	*****

Table 1: Relevance of the Automotive application for key technology area within HTSM

The focus on the automotive industry chosen in the acceleration agenda is also intended to create connections with other innovation domains and key areas at a concrete (application) level in the short and long term. It is clear that the technologically important HTSM areas can play a significant role in the future of automotive in the Netherlands. However, the importance of automotive for the technology sector is also considerable, as shown in table 2.

	HTSM	Automotive	
Employment	500.000	55.000	11%
Productionvalue [10^9 Euro]	165	38	23%
Exportvalue [10^9 Euro]	70	32	46%
HTSM projects 2024/25 [#]	125	5	4%

Table 2: Economic importance of the Automotive sector within HTSM[81]

In addition to Automotive, the Maritime, Aviation, and Logistics sectors are also important for the Sustainable Mobility innovation domain, as defined within the HTSM top sector. This confirms the importance of the relationship between these areas.

Aviation and Maritime

The technologies important to these sectors often share a common foundation with those in the automotive sector before they are developed for their specific end applications. Coordination in prioritization and cross-sector collaboration therefore holds significant potential. The reliance on partially shared infrastructure (e.g., ports, but also ICT) also shares many similarities.

Topsector Logistics

In logistics and mobility, the road vehicle car plays an essential connecting role alongside other modes of transport. The technology deployed in the various modes (aviation and maritime) has developed more or less independently. However, digitalisation is increasingly (virtually) linking the use of these different modes. Automation and robotization will also increasingly create a physical connection in the future, leading to a «physical internet.» This is particularly true in locations where transshipment takes place: ports, airports, and distribution centers. It is precisely in these locations that, in addition to a very high-quality digital infrastructure, there is also a great need for ZE energy infrastructure (and its smart use) for the other modes of transport as well.

Topsector ICT

Digitalisation in vehicles is booming (SDV), not only in logistics but also in mobility. ICT and its infrastructure connect virtually every logistics link across modalities and pave the way to robotization. Its role in traffic management is also growing, and there too, it paves the way to robotization.

Topsector Energy

The electrical infrastructure required for electric driving is rapidly developing. The petrochemical industry and companies active in the gas sector are demanding significant commitment to hydrogen.

SME's, startups and scale-ups

The importance of SMEs, startups, and scale-ups is also crucial for the automotive sector and technological innovation within it. They can be particularly important when it comes to cross-sectoral collaboration at the intersection of sectors. Innovation incentive instruments that also focus on «groundbreaking» in this sense are important (see also the incentive programs below). The automotive sector touches on its priorities areas within this Roadmap and the Acceleration Agenda, but like other sectors, it also benefits from a broad scientific and technological base.

9 Circularity, manufacturing and materials

The Dutch automotive industry is a key part of the country's high-tech manufacturing sector, employing around 55,000 to 60,000 people. Major companies like DAF Trucks, Scania, Setra, Hyster-Yale, VDL, Tata Steel, Bosch Transmission Technology, NXP semiconductors and TomTom lead the way, alongside numerous SMEs. In recent years, the industry has seen substantial changes, driven by green mobility, digitalisation, and a shift from component suppliers to full-service system providers.

Although core principles like reducing costs and improving quality remain, the industry is evolving rapidly. Circular economy principles and artificial intelligence have added new dimensions to production strategies. Lean manufacturing and Six Sigma are widely applied to reduce waste and monitor quality. Integrated IT systems, including ERP and WMS, are now essential in optimizing both internal and external logistics.

Technology is at the heart of modern production. Digital, data-driven factories and assembly lines have replaced older, manual systems. The integration of AI supports self-managing manufacturing systems, while additive manufacturing (3D printing) allows for more complex and customized products, produced efficiently and at lower cost.

Regulatory pressures are intensifying. EU initiatives like the Circular Economy Action Plan and the Eco-design Directive demand significant reductions in emissions and greater energy efficiency throughout the product life cycle. Although some progress has been made, the sector is not yet fully aligned with these goals.

The COVID-19 pandemic exposed the fragility of global supply chains and underscored the need for local production and flexible systems. Manufacturers must become more adaptive to fluctuating demands, increasingly operating on a "Local for Local" basis. This requires not only technical upgrades but also a rethink of business strategies and organizational agility.

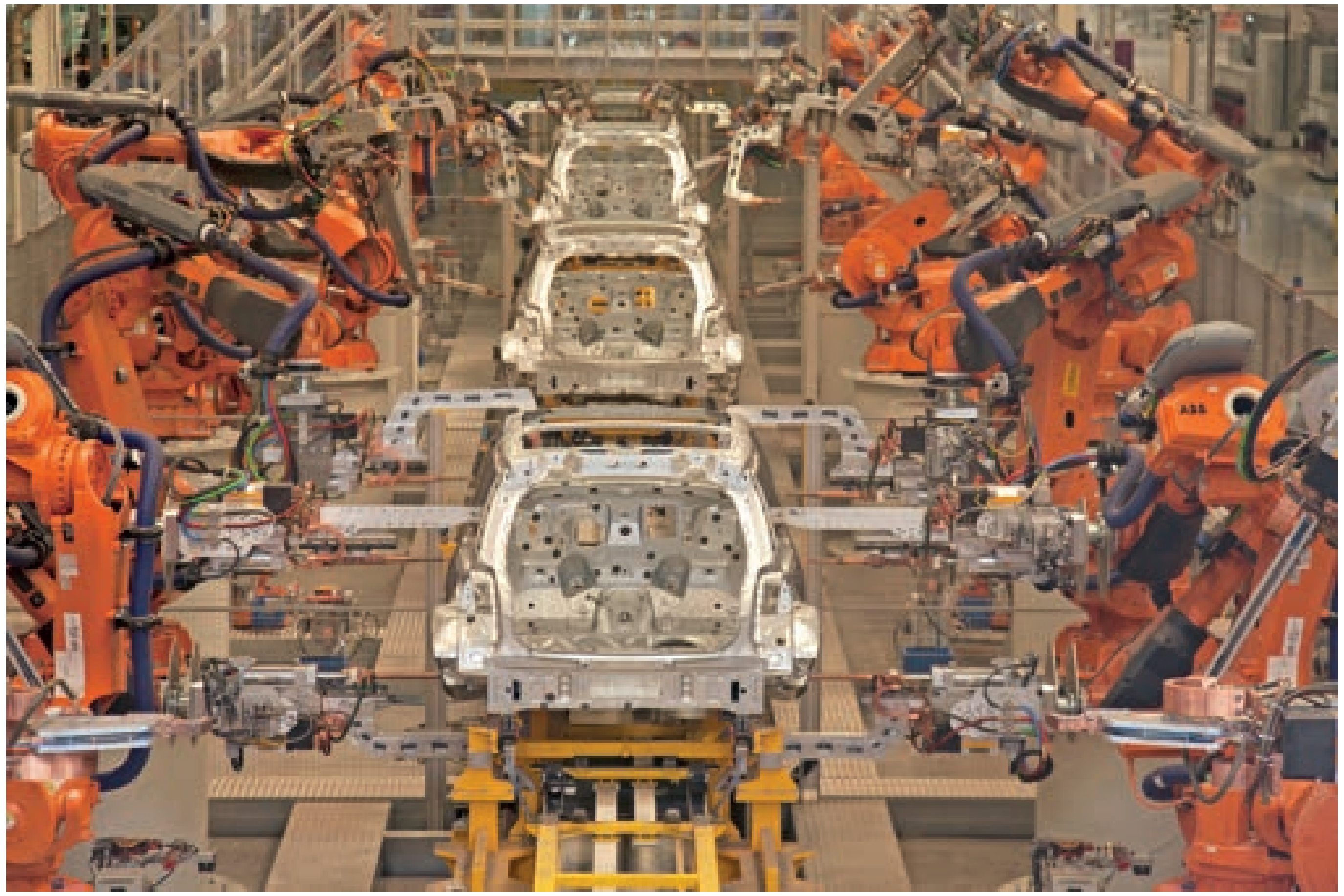
Looking forward, the future of automotive manufacturing in the Netherlands will center around four main pillars: sustainable and circular production, smart and data-driven manufacturing, high-performance and flexible equipment, and the use of new, innovative materials. Sustainability includes reducing CO_2, nitrogen, and waste emissions, and moving towards energy-neutral production. Social wellbeing also plays a role through better human-machine collaboration, improved ergonomics, and increased employee satisfaction. Smart factories will be digitally integrated, paperless, and connected via IoT, enabling real-time monitoring, remote control, and predictive adjustments. These environments support faster cycle times and greater flexibility. New manufacturing equipment must be modular, precise, and user-friendly. Systems need to shift rapidly between small and large series production while ensuring zero-defect outcomes. High-precision micro-manufacturing and adaptive planning tools are central to this development. Material innovation is also critical. Lightweight composites, smart materials, bio-based and recycled inputs are being adopted to meet sustainability goals. Technologies like 3D printing will support both advanced structural designs and efficient use of resources.

AI enabled predictive maintenance, reduces downtime by identifying mechanical failures before they occurred. Specialised AI applications carry out automated root cause analyses to identify the causes of quality deviations. In addition, AI applications monitor the condition of the machines in the production line. This allows problems to be recognised at an early stage and avoided through intelligent, proactive maintenance planning. Overall, these AI approaches promise significant increases in efficiency, quality improvements and cost savings that can be realised in the short term.

The enormous capabilities of AI were evident not only in the amount of data to be processed, but also in the speed. An artificial intelligence (AI) program of Microsoft has identified a material not found in nature that could reduce the amount of lithium used in batteries by up to 70%. After just 80 hours, 18 materials were identified that can now be used for further research. Normally, this process in research takes several years or even decades.

In conclusion, to remain globally competitive, the Dutch automotive industry must embrace this transformation. With over 60% of the sector's workforce involved in manufacturing, especially vocationally trained professionals, this shift has wide-reaching economic and social implications. Collaboration between industry, education, and research institutions will be key to ensuring a sustainable and innovative future for automotive manufacturing in the Netherlands.

In vehicle design, development, material research, integration of AI, machine learning and big data methodologies accelerate innovation cycles, and facilitate the search for suitable replacements for critical materials[82].



10 Priorities

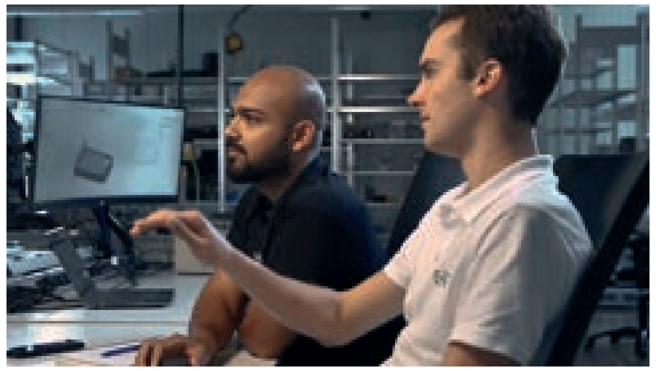
10.1 Acceleration Agenda

The priorities of the Dutch automotive industry are largely reflected in a series of large joint projects that have been initiated in recent years, some of which have (almost) been completed. Of the seven projects listed in Table 3, five focus on technology that contributes to CO_2 reduction in mobility. The other projects focus on technology necessary for automating vehicle driving. Within these projects, the emphasis is on relatively close-knit applications and technologies, their integration, application, and connection with technology that often originates from other sectors. Sustainability and digitalisation are therefore central.

Project	# Partners	Programme
Green Transport Delta-Elektrification	26	RDM
Green Transport Delta-Hydrogen	19	RDM
Digital infrastructure (DITM)	20	Groeifonds
Hydrogen technology for HD	28	Under preparation
Digital infrastructure		Under preparation
Integral HD energy supply	29	RDM
Battery Technology (BCC)	60	Groeifonds

Table 3: overview of major Dutch innovation projects from the automotive industry. Of the seven projects listed here, five are currently underway and two are on hold due to the termination of growth fund financing. [83], [84], [85], [86], [87].

The Dutch automotive industry recently outlined its short- and medium-term priorities in an acceleration agenda, structured around incentive projects. These projects are based on knowledge, technology, and innovation. The short-term focus is on accelerating the application of these innovations, which significantly contribute to the transitions and the economic position of the industry in the Netherlands, through incentive projects (collective market development). The longer term focus is primarily on the knowledge and innovation base of the Dutch industry, thus forming the foundation for future incentive projects and the associated social and economic development. The medium- and long-term priorities for innovation are outlined further in this chapter.



The PPP Innovation Scheme (PPS-I) encourages public-private partnership programs and projects in the high-tech systems and materials sector that develop innovations that contribute to urgent transitions, utilize technologies and applications from our innovation domains, and/or contribute to the missions within the Knowledge and Innovation Agendas of the mission-driven innovation policy[88].

10.2 Overview of 'impuls' trajectories from the Acceleration Agenda

The acceleration agenda defines 5 pathways in the areas of sustainability, digitalisation and circularity.

Sustainability:

<u>Electric Charging Infrastructure</u>
Accelerating the availability of high-speed electrical infrastructure on main logistics corridors. This means greater emphasis on corridor charging in addition to ZE zones to ensure investment security for logistics companies and thus the real uptake of volume in the market (as is happening in Germany, for example).

<u>Battery Technology and Infrastructure</u>
In the short term, this involves assembling battery packs and battery management. Several companies have developed technology or production methods that could represent significant improvements compared to the current state of the art. In the longer term, this also involves new battery technologies (solid-state batteries) and the reuse of (scarce) raw materials.

<u>Hydrogen-powered vehicles and infrastructure</u>
Hydrogen infrastructure; availability and affordability of (green) hydrogen, keeping all transition paths based on hydrogen (e.g. hydrogen combustion engines), fuel cell and e-fuel infrastructure open.

Digitalisation

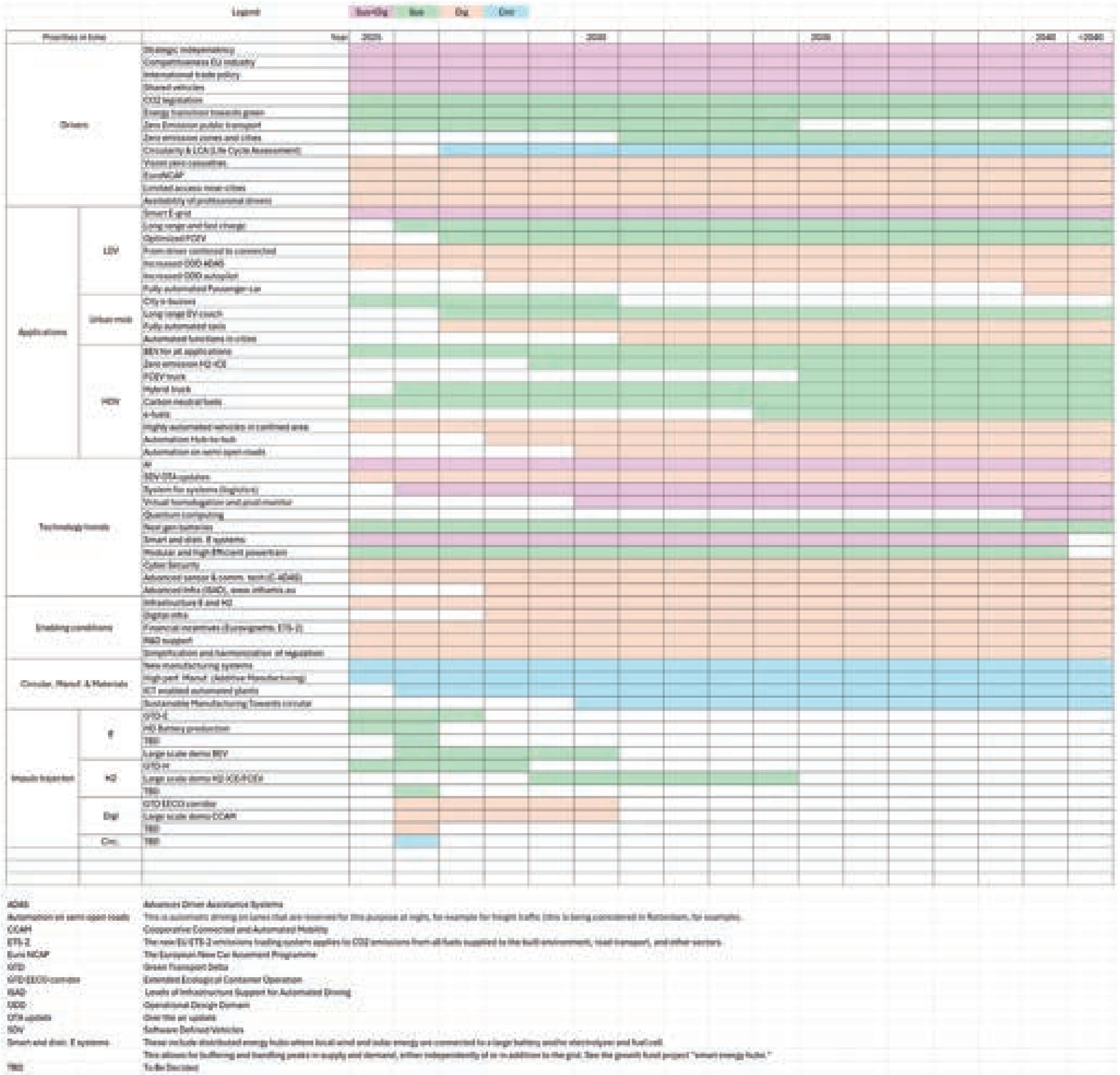
<u>Automation and robotization of vehicles and vehicle systems</u>
Data and software infrastructures that enable and support the automation of the logistics process (physical internet) and the integration of associated vehicles (software defined vehicles and automated vehicles), including safety and security, and an innovation-friendly experimental and approval regime.

Materials and circularity and production technology

Material availability and circularity.
The sufficient availability of strategic materials (e.g., for batteries) and the need to use materials in a circular manner will become even more important for industry in general, but also for the automotive industry as a major consumer.

10.3 Overview of Automotive Priorities and Incentive Programs

The table below links the key economic and social developments for the automotive industry to the various applications and priorities (incentive programs) for the Dutch automotive industry. Within these programs, incentive projects have been (or are being) defined to accelerate the transition from innovation to market application. They are also crucial for concretizing collaboration across sectors and with the government. They also provide a framework for innovations necessary for these programs in the long term. The industry strives to further accelerate these priorities and distinguish itself by achieving a leading position in the short and long term. However, the incentive programs do not replace the technological innovation programs that are necessary at an earlier stage. It is important that expertise and technology are developed and maintained on the application and enabling lines. The incentive programs can serve as a catalyst in this regard.



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