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COMMISSION STAFF WORKING DOCUMENT

Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility package

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Contents

I. Summary

Policy background

Recent years have seen a profound economic and societal transformation pushed by the energy transition and the 4th industrial revolution, with new technologies and business models bringing disruptive change to the transport sector that allows for completely new mobility services and logistics solutions.

Europe needs a better framework for joint action on transport research and innovation if it wants to fully exploit the opportunities this radical transformation brings. Systemic solutions and the development of vehicles and vessels technology need to be better synchronised across modal silos, to deliver resource-efficient multimodal solutions for door-to-door mobility and logistics, based on clean energy, enabled by digitalisation and harnessing the potential of social innovation.

This Staff Working Document is being presented as part of the 2017 package for clean, competitive and connected mobility[1]. It delivers on the European Commission's Strategy for low emission mobility adopted in July 2016[2] under the Energy Union[3], thus complementing the "Accelerating Clean Energy Innovation" Communication[4] and the Strategic Energy Technology Plan[5].

To address the urgency, the magnitude and complexity of the transformation that the transport system is undergoing, the present document addresses current and future challenges in an integrated manner through 7 innovation roadmaps. These roadmaps reflect the 'state of the art' of technologies, identify focus areas for research and innovation and actions to enable and deliver a systemic transformation of the transport system in the short-term (2018-2020) and in the medium- to long term (towards 2030 and up to 2050).

The document also outlines a process for the implementation of the roadmaps that shall ensure the link with policy making and programming of research and innovation funding.

Innovative transport technologies and mobility solutions are needed…

The mobility system is facing multiple challenges. In road transport alone, 25,500 people lost their lives to accidents in 2016 and 135,000 people were seriously injured[6]. Transport remains largely dependent on oil which means that under current trends CO2 emissions from transport would only decline by 11.4% between 2005 and 2050[7], making transport the largest contributor of CO_2 emissions in the EU after 2030. Air pollution caused by transport already today presents a major health problem in European cities[8]. Transport is also generating significant noise, affecting sleep, causing annoyance and cardiovascular diseases, with at least 10 000 premature deaths in Europe every year[9] Already today, the economic

[1] Commission communication on 'Clean, competitive and connected mobility' to be adopted on 31/05/2017 (link)
[2] A European Strategy for low-Emission Mobility (link)
[3] Energy Union: A framework strategy for a resilient energy union with a forward looking climate change policy (link)
[4] COM(2016) 763 final (link)
[5] https://ec.europa.eu/research/energy/eu/index_en.cfm?pg=policy-set-plan
[6] Road fatalities per million inhabitants, CARE (EU road accidents database) or national publications (link)
[7] EU Reference Scenario 2016 (primes): in 2030 90% and in 2050 86 % of the transport energy needs could still be covered by oil products(link)
[8] More than 467.000 premature deaths were attributed to exposure to high concentrations of particulate matter in 2013 (European Environment Agency (EEA) report 'Air Quality in Europe – 2016').
[9] European Environmental Agency: https://www.eea.europa.eu/soer-2015/europe/noise

cost of congestion is estimated at 1 per cent of EU Gross Domestic Product (EUR 100 billion). At the same time freight and passenger traffic are expected to grow significantly.

That means that research and innovation in transport can, and must make a real difference to the daily lives of Europe's citizens.

But these challenges also present a major opportunity that the EU industry must seize. European manufacturers of transport equipment and companies developing mobility solutions are among the leaders globally. Together with the service industry, they represent one of the most important employers in the EU and employ directly around 14 million people in 2014, representing 7.2 % of the EU Gross Value Added[10].

With Europe's transport system relying already to a significant extent on transport modes other than road (rail, waterborne, aviation, active mobility), the European industry has the chance to lead the transition towards the user-centric, integrated and truly multimodal transport system of the future.

… in priority areas

Throughout 2016, the European Commission consulted widely with a wide range of transport experts and stakeholders on a forward looking and focussed agenda for research and innovation in transport. The consultation led to the identification of 7 priority areas that cut across the different modes of transport. It also underlined the need to focus on the needs of users instead of existing capacity and to ensure an unprecedented and coordinated mobilisation of all transport sector players, public and private, including policy makers and the civil society

The seven priority areas are:

1. **Cooperative, connected and automated transport**
   There is consensus that cooperative, connected and automated transport can make transport more efficient, safer, inclusive and sustainable. Focus areas for research and innovation are: the co-existence of automated and non-automated systems, user needs, social acceptance, socio-economic impact of digital technologies, their influence on behaviour, including effects on CO2 emissions and resource efficiency, human-machine interaction, new types of vehicles and issues related to the data economy.

2. **Electrification**
   Electrification of transport, not only in road but also in other modes and as a systemic solution to decarbonise transport and energy systems, can reduce Europe's oil dependency and contribute to decreasing CO2, air pollution and noise from transport. Advanced power-train technologies and new vehicles architectures, including weight reduction, improved aerodynamics and rolling resistance and the development of components for electric vehicles are in the focus. The roadmap also addresses interfaces between vehicles and recharging infrastructure and cross-cutting issues such as new materials, advanced production systems and information and communication technologies, especially in relation to advanced energy storage systems.

3. **Vehicle design and manufacturing**
   The shift towards cleaner energy sources, connectivity and automation depends on the capacity to design and manufacture vehicles and vessels integrating these new

[10] In 2014 transportation and storage services (NACE H) directly employed more than 11 million people, accounting for 5% of total employment, and represents 5.1% of EU Gross Value Added. Manufacture of transport equipment (NACE C29 and C30) provided an additional 2.1% in terms of Gross Value Added and employs around 3.1 million people.

technologies without compromising safety, comfort and affordability and minimising lifecycle impact on the environment and on energy use. Focus areas of this roadmap are shortened cycles for vehicle design, development and manufacturing, new vehicle concepts, business models and modular vehicle architecture, as well as processes for reducing the environmental impact of manufacturing and recycling and remanufacturing.

4. **Low emission alternative energies for transport**
   Parts of aviation, waterborne and road transport may have to rely on combustion engines for the foreseeable future. This roadmap takes stock and outlines possible options for research and innovation to enable a wide-spread use of synthetic fuels, hydrogen (including fuel cells) and advanced biofuels as well as fuel blends and engine optimisation. New high efficient, low polluting combustion engines in combination with electrification and applications combining electrical, fuel cell and renewable fuels are addressed as well.

5. **Network and traffic management**
   Digitalisation will allow for better management of traffic streams and to optimise the transport network across current modal restrictions. Focus areas are actions to help developing and testing a future transport network that enables optimal traffic mix and circumvents temporary capacity limitations. This includes improving the interfaces between systems used in specific modes and ensuring interoperability, to make best use of existing infrastructure and accommodate changing demand and supply situations in real-time, without additional burden for users.

6. **Smart mobility and services**
   Innovation has a strong impact on transport demand, making transport more efficient and sustainable, in particular in cities, by fostering multi-modal transport solutions and avoiding unnecessary transportation. Smart mobility services also serve the social inclusion of those who are currently limited in their mobility. Focus areas identified by the roadmaps are urban mobility, demand and land use management, moving passengers to more sustainable modes of transports, smart mobility services in passenger transport , including 'mobility as a service', as well as in freight and logistics.

7. **Infrastructure**
   Innovative infrastructure design and operation can drastically improve the efficiency, safety and security of the transport system and reduce greenhouse gas emissions from transport operations over the entire lifecycle of the infrastructure. Focus areas of this roadmap are governance, the charging, interoperability, lifecycle optimisation and efficient operation of infrastructure.

The actions identified in the 7 priority areas are interlinked and support each other. For example, technology for cooperative, connected and automated vehicles (roadmap 1) will serve societal needs only if well integrated in concepts for sustainable smart urban mobility (roadmap 6). The safe operation of these vehicles very much depends on the right infrastructure being available (roadmap 7). Electric vehicles for different uses (private, freights, public transport, roadmap 2) can ensure sustainable mobility and a lower energy bill for Europe (roadmap 4), but this depends on improved vehicle design and manufacturing (roadmap 3) and a suitable infrastructure (roadmap 7), and is being leveraged by a better network and traffic management (roadmap 5).

Governance

More coordination of transport research and innovation efforts at national and European levels is needed to create synergies and steer joint implementation of research and innovation priorities. To this end, representatives of Member States and relevant transport stakeholders (transport related European Technology Platforms, industry, academia and civil society) will be consulted on a regular basis on the innovation roadmaps presented in this document.

This process will, *inter alia*, address the need to:

- Ensure a regular dialogue on innovative solutions for sustainable transport and mobility and discuss joint initiatives,
- Allow for synergies, economies of scale and technology transfer through an integrated, cross-modal approach,
- Focus financial support to research and innovation, linking EU funding closer to the long term objectives of EU transport policy and those of other policies, notably energy, climate and industrial policy.

A new information and monitoring tool - the Transport Research and Innovation Monitoring and Information System (TRIMIS) - will be set up to follow up transport research and innovation actions and provide feedback to policy and decision makers, including interfaces with the energy sector's corresponding tool (SETIS).

II. Transport research and innovation roadmaps

1. Cooperative, connected and automated transport

Connected and automated transport (CAT) technologies can contribute to increase the efficiency and safety of the transport system. The introduction of these new technologies and services can improve traffic flows[11], optimise the use of infrastructure, lower noise levels, shift greater volumes of passengers' traffic toward public transport, increase the efficiency of goods transport and foster the emergence of multi-modal transport solutions. In all transport modes connectivity and automation could deliver significant benefits in terms of fuel economies. Examples of quoted gains are e.g. 8-13% for trucks (platooning)[12] and up to 25% through automation of existing vessels and more efficient vessel operation[13]. Through emerging innovative mobility concepts, as enabled through connectivity and automation, larger contributions to fuel and emission reduction can be expected, e.g. through modal shift to greener modes and higher vehicle occupancy rates for passengers.

Before connectivity, automation and smart services can take a significant place in the European transport system, a number of technical and non-technical challenges need to be resolved. Although a number of demonstration pilots of CAT technologies are already taking place in Europe, there is still a great need to test the technological readiness, reliability and safety of automated transport functions in complex traffic situations at large scale. Moreover, ICT applications (e.g. connectivity, big data, cloud computing, deep learning) for increasing the performance of automated transport technologies, a regulatory framework supporting the fast introduction of these technologies acceptable levels of cybersecurity as well as new business models are some of the key issues to be addressed. Equally important will be to develop and test innovative mobility services along with CAT technologies and traffic management systems, which can optimise the transport system while keeping a sufficient degree of flexibility and adaptability to address users' changing demands.

1.1. State of the technology development

The levels of maturity, acceptance and real-life implementation of technologies and systems for both the automation and the connectivity element vary largely between individual modes. Some applications have already been in use for a considerable time. Commercial aircrafts have elements of automation since decades and some metro lines and airport people-movers have also been fully automated since long. The advent of big data and Internet of things together with relatively cheap and ubiquitous communication infrastructure provide a large potential for developing new services and vehicle functions[14]. However, with higher levels of automation and connectivity there is an increasing risk of cyber-threats on all types of transport vehicles and vessels and cybersecurity is a growing concern in all modes.

a) Road

Many car and truck manufacturers are working on the development and roll-out of vehicles with increasingly higher levels of automation, paving the way from current Advanced Driver Assistance Systems (ADAS) towards full vehicle automation. An increasing number of

[11] Congestion is costing yearly the EU 1% of GDP, see Transport White Paper IA (link).
[12] SARTRE project: 'D.4.3 Report on Fuel Consumption', Applus+ IDIADA, 2014
[13] Pathway to low carbon shipping. Abatement potential towards 2030. DNV report, 2009.
[14] McKinsey: Monetizing car data: New service business opportunities to create new customer benefits, 2016

high-end vehicles produced by European car manufacturers are already equipped with partial automation technologies (Automation Level 2) [15], consisting of a combination of driver assistance systems like Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA). The next step will be the introduction of vehicles in which the driver can choose whether to drive manually or not. It is expected that passenger cars with conditional automation functions on highways (Automation Level 3 - full driving is performed by an automated driving system with the expectation that the human driver will respond appropriately to a request to intervene in real traffic conditions) will enter the market around 2020[16]. Fully autonomous vehicles which can drive without human intervention and operate door-to-door with full freedom of movement are expected to be available on the market by 2025-30[17] [18].

In the highly competitive market for cars and trucks, ADAS and automation, and their potential leverage into driver comfort and safety, are important selling points. Automated trucks are being tested on motorways in several European countries as well as in the US and Japan. Several demonstrators of truck platooning in Europe[19] have given useful insights in issues such as interoperability when crossing borders.

Automated systems for user-friendly public transport have been developed and demonstrated, mainly driven by public and EU funded research. Examples are the EU-funded projects CityMobil 1 and 2[20]. These automated urban transport systems normally use a dedicated track. To maintain road user safety their speed is currently too low to be competitive against conventional public transport. Several demonstrations have been made, and there are examples of successful implementation in public areas, notably in the Netherlands. Original Equipment Manufacturers (OEM) of last mile shuttles have appeared in the market and are willing to lead the first wave of non-research, commercially available and roadworthy transportation.

Small automated vehicles for individual or collective transport of people and goods are also being tested. They can be fully automated under normal operating conditions, do not require human interaction and make use of information from a traffic control centre, the infrastructure or from other road users. Examples are small vehicles (for transporting up to 20 people) and vehicles for mass transport (more than 20 people)[21] which use exclusive infrastructure or share space with other road users. They can use various types of automated systems, either for guidance or for driver assistance; and always have a driver, who can take over control of the vehicle at any time, allowing the vehicles to use the public road. First developments are under way for deploying small automated vehicles (sometimes called road drones) for urban freight distribution.

Connectivity has so far been seen as an enabling technology for vehicle automation, but is now emerging as a much more prominent aspect. Connected vehicles that are currently available offer services e.g. internet surfing, info traffic, GPS, E-call, vehicle-to-vehicle and vehicle-to-infrastructure short-range communication, etc. but do not carry out automated

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[15] The SAE International standard J3016 identifies six levels of driving automation from "no automation" (level 0) to "full automation" (level5).
[16] https://www.audiusa.com/newsroom/news/press-releases/2017/01/audi-and-nvidia-to-bring-fully-automated-driving-in-2020
[17] http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry
[18] ERTRAC Automated Driving Roadmap, Version 5.0, 2015 (the roadmap is currently under update. The new version supports the mentioned timeframe.
[19] One recent example is the "European Truck Platooning Challenge" (initiated by the Dutch Presidency). This challenge was a successful experiment of cross-border, large-scale testing of platoons on open roads in mixed traffic.
[20] CityMobil 1 and 2 (link)
[21] See http://www.polisnetwork.eu/uploads/Modules/PublicDocuments/Phileas%20advanced%20Bus%20System.pdf

driving tasks yet. To maximise the benefits from connectivity, interoperability is a pre-condition (i.e. all vehicles can communicate with each other but also with the infrastructure in all Member States). Services can be delivered over either a dedicated network or a commercially available network like the cellular communication network. Connectivity will enable and further expand the performance of automated vehicles because it makes distributed information and big data accessible e.g. for prediction of road-user behaviour and route planning.

b) Aviation

In civil conventional aviation (i.e. activities linked to manned passenger and freight air transport) CAT is progressively being introduced. The prime reasons for more automation are increased airworthiness and operational safety levels, increased throughput, effectiveness and cost efficiency. Many important CAT technologies for aviation are addressed in the Clean Sky Programme[22], which focuses on CO_2 emission reduction through e.g. aircraft operational and technical improvements, or the SESAR project in both development and deployment phases[23] for Air Traffic Management (ATM). They are key contributors to the Flight Path 2050 air traffic management goals[24] (mainly in the mobility, safety & environment challenges).

ATM is evolving in accordance with the SESAR programme and the European ATM Master Plan[25]. SESAR has been instrumental in developing new features requiring a high level of automation. Examples include Air Traffic Control (ATC), which has been virtualised for decades, as well as remote, virtual airport control towers, virtualisation, and a System-Wide Information Management (SWIM). The SWIM concept is providing connectivity between all airspace actors and enabling data sharing between them. This will open up many more possibilities for automation in the air-traffic system and for greater efficiency and CO2-emission reduction. SWIM could eventually become a blueprint for a transport-wide information-sharing network.

Aeronautics design is evolving towards higher levels of automation. Smarter avionics systems are gradually being integrated into the aircraft systems (e.g in the cockpit) with an ever increasing level of automation. Automation on board comes together with increased levels of safety and also increased efficiency and predictability. It has also been the only option for enabling operations in low visibility conditions. Research has already been conducted on moving from a 2-pilot crew to a fully autonomous aircraft via single pilot, optional piloted and Remotely Piloted Aircraft Systems (RPAS- drones), notably in the context of human factors and artificial intelligence.

Substantial progress has been made in the area of miniaturised low-cost on-board Detect And-Avoid (DAA) systems, instrumental to allow small drones to avoid collisions with other airspace users. More validation in challenging environments is however required. Significant research has been conducted on drones themselves, nevertheless new applications are developing at high speed in all sectors and air traffic insertion is still a showstopper.

Modern data connectivity in air transport is however developing at a slower pace: aircrafts are connected to ATC centres through radio, with information being shared having many

[22] http://www.cleansky.eu/
[23] http://www.sesarju.eu/
[24] http://www.acare4europe.com/sria/flightpath-2050-goals
[25] https://www.atmmasterplan.eu/

aircrafts on the same frequency. Connectivity now offers new services to passengers through on-board Wi-Fi and innovative ground processes, based on advanced identification and payment systems (e.g.transport ticketing, significantly improved customer information and handling systems)[26]. New services can also be developed for the air transport industry, e.g. for engine performance, with potential contributions to CO2 reductions notably those linked to measurements and prediction of environmental conditions.

c) Waterborne

Through better data integration and improved monitoring, CAT will contribute to maintain a competitive shipping industry in Europe as well as improve security in the transport systems. Similarly, to the other modes, safety is a main area where CAT is expected to provide improvements. In today's shipping industry, the human factor remains the most important underlying cause of marine accidents. For shipping, the safety of shipping must also be considered in environmental terms where the risk of very rare, but highly severe accidents remains.

Ship automation is well advanced with most modern ships and vessels being equipped with target detecting radars, automated warnings for crossing traffic as well as autopilots and track pilots making use of satellite positioning systems. Automatic Identification System (AIS) transponders on many sea or inland waterways vessels send position and speed data to other ships and shore to enable better shore support and improved anti-collision decision support. Technical systems on board have a high degree of automation and today, all ship systems can in principle be remotely controlled from the bridge or even from shore, although the latter is not generally allowed by the relevant authorities. Ship Autonomy is a new field with little technology currently available. Some demonstrations have been made of suitable technology, e.g. in the MUNIN project[27], but this is still on a low technology readiness level. Automation systems, such as dynamic positioning, contain some elements of autonomy. Automated berthing has been demonstrated in some special cases.

Traffic Management is simplified by many ships having AIS transponders and signals/information being transmitted to Terrestrial-AIS receivers on land and when out of reach, to SAT-AIS. Shore support in the form of River Information Services (RIS) or Vessel Traffic Services (VTS) for sea areas is common. Past and ongoing EU-projects, such as Mona Lisa and STM[28], are looking into more advanced traffic management schemes. Inland waterway projects are looking into further harmonisation of RIS, and will bring RIS one step further to integration with other transport modes.

Digital Connectivity is a prerequisite for all above mentioned improvements. It is available on the physical carrier level (satellite or land based mobile communication) and it is expected that commercial interests will provide ever increasing capacity and coverage as demand from paying customers increase.

d) Rail

CAT technologies are already well embedded in selected market segments of rail-bound transport, specifically in metro systems. The highest Grade of Automation (GoA) 4[29] - a

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[26] For the drone sector connectivity is and will become even more, essential in management of the fleet (e.g. RPAS operators and others, global tracking from Radars / ADS-B / ADS-C to satellite monitoring, collision avoidance (TCAS): connection between aircraft, being extended (TCAS–U) to deal with unmanned air vehicles).

[27] See http://www.unmanned-ship.org

[28] http://stmvalidation.eu/

[29] GoA (Grade of Automation) levels 0 – 4 according to International Electrotechnical Commission, International Standard 62290-1. Grade of Automation 4 refers to a system in which vehicles are run fully automatically without any operating staff on board.

fully automated driverless rail-bound system, exists today in metro systems e.g. in Copenhagen, Milan and Paris. Next to automatic operation based on the moving block principle (creating in real-time safe distances between moving vehicles), The GoA 4 system is responsible for door closing control, dealing with obstacles on track during the journey and emergencies. This GoA level was mainly introduced on newly constructed metro lines, in an isolated environment not accessible for third parties. Solutions were not standardised and expensive.

With the technological progress in the 1990s, CAT technologies were also developed and deployed in other sectors of rail transport (light rail, suburban rail, long distance rail) based on common standards. However, due to a much diversified European rail landscape, characterised by various safety and operational requirements, technical solutions as well life-cycle stages, the implementation of CAT technologies is progressing slowly and this lowers the competitiveness of railway sector.

The Strategic Rail Research and Innovation Agenda (SRRIA) and related roadmaps for various parts of rail-bound systems as well as the Master Plan of the Shift2Rail Joint Undertaking address directly and indirectly several aspects of automation and connectivity. The existing state of the art with regard to sector vision, related research and innovation policy measures and the ongoing Shift2Rail JU activities creates a good reference point for an automated and connected roadmap for the part of rail-bound transport.

1.2. Focus areas for action

A customer-centric, intermodal integrated transport system approach is proposed to ensure that benefits for the transport system as a whole in terms of efficiency, reduction of environmental impact, safety and health are maximized. This will help to move away from the "silo thinking" or mode-specific approaches by supporting seamless door-to-door transport solutions for people and goods and value-added services using data generated by connected and automated vehicles or vessels while at the same time ensuring data protection and right to privacy. With the help of CAT, new efficient and flexible vehicles, vessels, trains or drones can be developed, which open many interesting opportunities for new integrated solutions and services for freight and passengers. The integrated transport system approach includes policy actions to support transport demand management, the integration of logistics systems and last mile transport services as well as policy guidance and support, notably legal and regulatory requirements and socio-economic issues. It is furthermore important to develop and maintain close cooperation with other regions, particularly the US and Japan, to exploit synergies, reduce redundancies and work towards a global framework and international standards for CAT technologies.

Focus areas are the successful development of CAT technologies, their swift deployment while ensuring industrial competitiveness, and the enabling framework.

Actions which are important for all modes and where an integrated and cross modal approach should be undertaken are presented below:

- **Active management of CAT technologies in an evolving mobility system** in which automated and non-automated systems will co-exist. This is essential both for the success from a business and operator perspective, as well as in terms of guaranteeing that public sector policy objectives are adhered to, without risking potential additional negative consequences. Transition principles will have to be developed between the existing and future solutions, for each mode and the overall integrated transport system as a whole.

- **User and societal acceptance:** more targeted research for user needs and requirements based on real-life applications in a variety of territorial settings (urban, rural) is needed. It is necessary to develop acceptance criteria for operation of different types of autonomous vehicles, including users' confidence when no "driver" is present. Novel data sources together with analytics can be key enablers to investigate human factors during system trials or implementation.

- **Socio-economic aspects:** Increased automation and connectivity in the transportation sector will have socio-economic impacts which need to be analysed. A major impact on the level of employees within transport can be expected. For example, in the rail sector Automatic Train Operation deployment, intelligent wayside, on-board measuring and monitoring systems and intelligent solutions at stations will require less staff. The social perception and acceptance of automation should be considered in the transition period moving to higher adoption rates and their impact on jobs both within Europe and worldwide should be monitored. Training and education considerations also need to be made.

- **Environmental and climate aspects**: For the environmental and climate impact of these technologies it will be important to anticipate and assess how they influence mobility behaviour and what CO_2 emissions and resources effects it entails.

- **Human-machine interface:** new ways to design the human-machine interface in the vehicles/vessels will remain an important field of research. There is a great potential to exchange experiences and best practices in that area between the modes.

- **Innovative hybrid vehicles:** enabled by big data, automation and connectivity, we might soon witness the advent of new vehicles, which do not fit into the rigid definition of current modes any more, both in terms of network infrastructure, propulsion, or loads being carried. These vehicles will need further attention in terms of research and innovation, standards and regulations.

- **Cybersecurity and data protection:** There is a clear need to create a good understanding of cyber security in transport, identify related risks, define and implement adequate levels of security against attacks for today's and future products. Acceptable levels of and principles for cybersecurity and data protection, which are critical in the broader issue of data access, must be developed and regular updates ensured. The EC is already working on the development of guidelines and measures to prevent unauthorized access to data from vehicles/vessels and infrastructure. More research is needed to provide the highest possible robustness against cyber-attacks. Deep learning effects should be incorporated.

- **ICT infrastructure to support the performance of CAT technologies**: Connectivity of vehicles is essential to increase the safety and performance of CAT technologies and development of cost-efficient and reliable connectivity solutions must be supported. CAT technologies must be compatible and interoperable at European level. There is a need to coordinate investments towards reliable communication coverage, exploit the full potential of hybrid communications where relevant, and improve the performance of location accuracy, benefiting from the use of GALILEO and EGNOS.

- **Optimised use of internet of things, big data and innovative data management and governance** needs to be researched for increasing the performance and efficiency of automated transport technologies, transport systems, mobility and freight delivery services. This includes data mining, access to and innovative uses of data sources, data analytics, innovative business models, and visualisation. It is also necessary to define technical specifications that can enable Internet of Things type applications over service data networks of variable quality and also in remote areas (a particular concern for waterborne).

1.3. Short-term research and innovation actions

The following paragraphs and tables identify the corresponding needs in terms of R research and innovation for successful technological development, actions for swift CAT deployment and increased competitiveness for the European industry, as well as essential enabling aspects. A short-term (until 2020) list of actions is proposed below.

	Successful technological development	**Swift deployment of CAT technologies and increased competitiveness of the European industry**	**Enabling framework, including new regulations/ legislation, pre-conditions, infrastructure**
LARGE-SCALE, CROSS BORDER DEMOS	Large-scale, cross-border demos for freight and passengers: (all modes and multimodal/door-to-door). 1) Develop and test shared, connected and cooperative automated vehicle fleets in urban areas for the mobility of all 2) Develop and test connected and automated heavy-duty vehicles in real logistics operations 3) Test the applicability of 5G connectivity to "Connected and Automated Driving" use cases 4) Large-scale, cross-border demonstration of highly automated driving functions for passenger cars. Demos will analyse different business models/implementation scenarios to meet the demand of different user groups in different regions and operating environments. Demos will consider the optimised use of digital technologies as the Internet of Things, Artificial Intelligence and Big Data for automation.		Knowledge and data platform(s) to enable MSs coordination and exchange of knowledge and data from demos **GEAR 2030 (Road)**: address important legal and regulatory issues and standardisation for connected and automated vehicles **C-ITS Platform(Road)**[30]: recommendations on C-ITS to use the potential for connected and automated vehicles **Round Table on Connected and Automated Driving** (Road) addressing digital issues Actions associated with the **The Letter of Intent on cross-border testing** signed by 29 European countries on 23 March 2017[31]
HUMAN FACTORS	Human centred design of automated vehicles - design of safe human-machine interfaces for vehicles with highly automated driving functions and the safe and controlled transfer between use cases of different SAE automation levels for all types of drivers.		
AUTONOMOUS WATERBORNE TRANSPORT	Develop and demonstrate to TRL7 a fully autonomous vessel within a realistic environment. Focus will be on first adopters (inland waterways, short sea shipping, ferries and urban water transport)		

[30] Based on the EU strategy outlined in the EC Communication "A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility" adopted in November 2016,.

[31] In this letter the countries engaged to further intensify their cooperation on cross-border testing of cooperative connected and automated mobility. This letter follows the Declaration of Amsterdam on cooperation in the field of Connected and Automated Driving.

DRONES	Explore and develop innovative technologies for pilot services such as transport network monitoring, (inter-) urban cargo including small-scale demonstration to underpin and expedite regulatory adaptation, solve Air Traffic Insertion (U-Space) as the essential enabler of drone service, standards validation and follow-on deployment in Europe.		
SOCIO-ECONOMIC ASPECTS	Analyse user and societal acceptance and assess impacts, benefits and costs of CAT.		
ENVIRONMENTAL ASPECTS	Assess CO_2 and environmental impacts of the new technologies.		
TESTING, & VALIDATION PROCEDURES	Testing, validation, certification procedures for highly automated driving functions under various traffic scenarios based on pilot test data.		

1.4. Outlook for research and innovation actions until 2030

Given the disruptive nature of CAT technologies, in particular in the road transport segment, a 2030 perspective is taken for the research and innovation actions outlined in the following tables, which describe research and innovation actions by mode as well as deployment related issues and enabling frameworks.

1.4.1 Road

The proposed research and innovation actions contribute to and complement the already ongoing EC initiatives in the area of Connected and Automated Road Transport, notably GEAR 2030, the C-ITS Platform and the Roundtable on "Connected and Automated Driving".

ROAD	**Successful technological development**	**Swift deployment of CAT technologies and Increased competitiveness of the European industry**	**Enabling framework, including new regulations/ legislation, pre-conditions, infrastructure**
SUPPORTING ROAD SAFETY	Resilient, affordable and sustainable sensors operational in variable conditions and road environments. Improved detection technology and perception intelligence.	Understand how different levels of automation in vehicles affect e.g. road safety and traffic flow, in a mixed traffic environment also including manually controlled vehicles and "non-vehicles".	Define (minimum) safety and roadworthiness requirements of higher levels of automation. Provide details for testing to ensure continuous roadworthiness for automated vehicles in use, on the market
	Develop Artificial Intelligence (AI), including Deep Learning, for road vehicles in the	Knowledge on human driver's / operator's understanding, use and acceptance of highly automated driving systems. Address driver attention and	Development and verification of common evaluation methodology valid throughout Europe, based on a common

	context of reduced engagement of humans in the driving task.	involvement in driving and other non-driving related tasks, and how this affects road safety. Tackle training needs and skills degradation with increased automation, as well as mixture of automation levels within and between vehicles, including different demographics and societal acceptance.	understanding of the safety, reliability and security of CAV. research and innovation should address safe operation in complex and mixed traffic situations.
			Identify essential changes in infrastructure, traffic rules and traffic management, and how improved infrastructure can boost the uptake of automated driving. Truck platooning and urban challenges are initial focus areas.
INFRASTRUCTURE, CITIES		Develop new business models for widespread deployment of connected automated road transport systems, including models for car-sharing for the mixed use of private and public vehicles. Include new actors entering the field.	Support municipalities to get prepared for deployment of connected and automated vehicles, and their integration into a wider transport system concept. A better understanding of users needs is necessary, and how they can actively benefit from CAT related investments.
BUSINESS AND COST ASPECTS			
SUPPORTING ACTIONS & NEEDS			
Assess impacts of different scenarios of vehicles automation on the transport system.			
Grant innovative solutions with the appropriate framework for their real-life testing and demonstration in certain geographical areas, even if not all procedures or requirements of the legislation in force are complied with.			
Identify **barriers for mass penetration** of CAT, as well as recommendations to overcome the barriers to ensure competitive role European industries. Include an understanding of how to produce transport system components at globally competitive costs, whilst still ensuring a safe and decarbonised transport system.			

1.4.2 Aviation

The following list represents the most relevant research and innovation actions leading to a successful deployment of highly competitive low-carbon CAT solutions in air transport, notably in terms of hybrid vehicles, new business models and their certification criteria. The proposed actions complement the Clean Sky and SESAR programmes already underway, the "Pilot Common Projects" implementation regulation (EU) No 716/2014 and the European ATM Master Plan. In parallel, the industry will progressively introduce worldwide air vehicle improvements developed through the Clean Sky programme.

AVIATION	Successful technological development	Swift deployment of CAT technologies and Increased competitiveness of the European industry	Enabling framework, including new regulations/ legislation, pre-conditions, infrastructure
SUPPORT LOW EMISSION CONTRIBUTORS			It is essential to develop the regulatory framework that prioritises low-carbon routings from gate to gate and to ensure that the CAT solutions are developed as to minimise CO_2 emissions. (closer to 2020 than 2030) Assess the potential benefits and impact of using CAT for air operations (including conventional civic air transport to fully autonomous vehicles and drones) on reducing CO_2 emissions.
DESIGN. MANUFACTURING, CERTIFICATION PRIORITIES	Design/manufacturing/certification of autonomous air vehicles and highly automated/virtualised systems should take into account all the safety and security aspects as well as the users' needs (citizens and air transport actors), specifically considering privacy and safety concerns, liability issues, risk quantification for insurance, nuisance of new vehicles/ new types of operations.		
CREW / MACHINE DECISION DELEGATION	Develop systems with the appropriate level of delegation of the decision between the machine and the crew (on board and /or on the ground), analysing risks and opportunities of changes to single pilot /RPAS[32] crew roles, ensuring social acceptance, creating appropriate certification criteria or ensuring communication links.		
	Future concepts of air traffic flow management which would be required to take due account of very high number of air vehicles, their mixed autonomy levels, the SESAR concept of operations incl. automated and virtualised concepts and changes in workforce (roles /responsibilities)		
DRONES	Assessment of the potential impact of drones on CO_2 reduction targets when responding to current limitations in any industrial sector as not to negatively impact the air transport sector's commitment on climate change, safety and security.	Develop innovative business models and efficient traffic management systems for transport services by drones for urban and remote areas.	It is important to offer a legal framework for research and development which is adapted to the rapid-change dynamics of CAT products, especially in the drone sector and their security

[32] Remotely Piloted Aircraft System

			threats.
Given the huge potential of drones for both CO2-emission reduction and economic growth, there is a need for **public monitoring of drone market development** both within Europe and worldwide[33].			

1.4.3 Waterborne

A number of important research and innovation priorities as well as actions in the areas of regulation, standardisation are proposed, which are essential to accelerate the deployment of CAT technologies in waterborne transport. Due to much higher investment levels and associated risks, it is expected that developments for deep-sea shipping will be slower than for short sea shipping, coastal shipping and inland waterways respectively.

WATEBORNE	**Successful technological development**	**Swift deployment of CAT technologies and Increased competitiveness of the European industry**	**Enabling framework, including new regulations/ legislation, pre-conditions, infrastructure**
COLLISION AVOIDANCE	Sensor systems and situation assessment for anti-collision: address human factors' caused accidents at sea by better sensor systems, "driver assistance" and other decision support systems on the bridge.		
	Anti-collision systems need to be further developed to support fully unmanned navigation for the realisation of fully or partially unmanned ships. Such systems need to be integrated with various other systems for voyage planning and execution, such as weather routing.		
VESSEL TRAFFIC MANAGEMENT (VTM)	Technical functionality of VTM Services – VTS at sea and River Information Services – RIS in inland waterways) must be developed to allow just in time arrival and traffic optimization to reduce congestion and fuel use. VTM needs to integrate and coordinate with commercial and logistics systems to provide just in time arrival functions		New legislation is required to enable the use of new VTM Systems and UMS in the EU. Updates to existing international legislation will also be required.
UNMANNED SHIPS (UMS)	New passenger safety and evacuation systems for unmanned ferries need to be		

[33] For more details, please check : http://science.time.com/2013/12/03/shopping-by-drone-could-be-good-for-the-environment/ http://dronefutures.org/3-environmental-benefits-drones/

	developed and corresponding legislation passed. Unmanned short distance ferries are a very interesting business and technical proposal.		
	Fully UMS concepts for short sea/inland and deep sea. This is interesting for moving transport from road to waterborne, it also may allow the use of alternative and low emission energy systems (fuel cells and batteries). The design of unmanned ships for deep see shipping can also provide significant energy savings.		
INCREASED AUTOMATION IN WATERBORNE	To improve connectivity and to increase automation on waterborne vessels, it is necessary to define technical specifications that can enable IoT applications over variable quality of service data networks. This includes further developments on the standardised VHF Data Exchange System in particular via low earth orbit satellites.	Develop acceptance criteria for operation of different types of autonomous ships including technical and operational risks as well as societal acceptance	Increased automation of ships will require some changes in ports, e.g. for maintenance of ships as well as increased automation also in approaches and docking. Ports serving unmanned ships will require new infrastructure for mooring and fine manoeuvres.
			Regulation of port policies towards automated and unmanned ships and vessels so that ships can easily call on different ports, without having to deal with different operational and policy principles. This may include adjustments to local port bylaws.
SUPPORTING ACTIONS & NEEDS			
A new management regime for zero-defects at sea - with higher reliability and preventive and predictive maintenance is required to support increased automation as well as autonomous ships. A large percentage of accidents in Europe is caused by defective technical systems. Current maintenance regimes on ships depend on human intervention and a large degree of in-situ replacement and repair of defective equipment during ship operation.			
Large-scale test facilities for autonomous vessels: Large-scale test facilities (in situ through assigned sea areas as well as virtually via EMSN) are major gaps with regards to development of safe waterborne CAT. This can be done on regional or EU level[34].			
Changed services of the pilots for periodically unmanned ships: As an example, pilots may have to operate from land with remote control. Pilots may also get a more active role in local port operations, taking over some responsibility from shore control centres.			
Examine whether legislation and standards for **approval of open integration systems** need to be changed. Ship systems are characterised by relatively low integration between different manufacturers' systems and significant difficulty in adding third party functionality into each system or across systems. Examine whether priority should be given to goal based standards rather than prescriptive test standards in a way that permits cost effective development and testing of new functions. Standards may be developed by the industry if legal			

[34] This is already the case as Norway has dedicated a sea area to this scope.

<table>
<tr><td>and policy actions enable new forms of open integration in ships</td></tr>
<tr><td>Standards for data exchange between ship and shore for more integration of ships into shore systems, including port and supply chain operations as well as operational support and third party services needs to be developed. Ongoing work in the context of IMO e-navigation, ISO, IEC and UNECE needs to be supported to develop suitable standards for full integration of the digital ship into the complete logistic and transport system.</td></tr>
</table>

1.4.4. Rail

The proposed research and innovation priorities complement the Strategic Rail Research Innovation Agenda (SRRIA) and related roadmaps for various parts of rail-bound systems as well as the Master plan of the Shift2Rail Joint Undertaking, which define already important actions to support the use of automation and connectivity technologies in the rail sector.

<table>
<tr><th>RAIL</th><th>Successful technological development</th><th>Swift deployment of CAT technologies and increased competitiveness of the European industry</th><th colspan="2">Enabling framework, including new regulations/ legislation, pre-conditions, infrastructure</th></tr>
<tr><td>AUTOMATIC TRAIN OPERATION (ATO)</td><td>Technologies for higher levels of automation (up to GoA[35] 3/4) in order to implement (ATO) in all rail market segments (high speed, mainline, urban, regional, and also freight lines).</td><td></td><td rowspan="4">Testing procedures: Higher automation in rail transport will require unified approval procedures, common operational rules and improved automation of testing procedures.</td><td rowspan="4">Intelligent, data driven measurement and monitoring to help increasing reliability levels of railway traffic. This will have to be supplemented by smart systems to measure and monitor the status of all railway assets and allow mapping and optimising energy flows within the entire railway system.</td></tr>
<tr><td>UNIVERSAL TRAIN CONTROL SYSTEM (UTCS)</td><td colspan="2">Development and seamless deployment of a new, adaptable and IP based communication system, as one of the building blocks of the future UTCS – Universal Train Control System. The UTCS will have to be a cost-effective solution that can be easily introduced for all rail market segments. Enablers and blockers of automation should be assessed.</td></tr>
<tr><td rowspan="2">DECISION AND ADVISORY SUPPORT</td><td colspan="2">The development and increased adoption of automatic and/or decision support systems, not only for operational purposes, can optimise the efficiency of resources usage lowering the overall costs. It will be necessary to manage the transition to complete automation and resilience, safety, security and cyber security while allowing the right degree of accessibility.</td></tr>
<tr><td></td><td>Adoption of Driver Advisory Systems to increase capacity and reduce energy consumption while reducing headways.</td></tr>
<tr><td>INTELLIGENT STATIONS</td><td colspan="2">Intelligent stations for a better customer experience by developing solutions to improve accessibility, capacity and security for passengers as well as the interconnection with other (automated) modes, incorporating intelligent measuring and monitoring systems, and various IT solutions.</td><td colspan="2"></td></tr>
</table>

[35] GOA = Grade of Automation; ranges from 0 to 4 (highest; fully automated without any on-train staff)

TERMINALS & WAGONS	Development and deployment of modern solutions for automatic coupling of wagons and automation progress in terminals and marshalling yards to increase speed of last mile handling and to contribute to rail competitiveness. Development of new autonomous, self-propelling rail freight wagons.	
LEVEL CROSSING SAFETY	Improve safety at level crossing through more automation in rail (e.g. obstacle detection) and road (e.g. information to driver, automatic brake of vehicle).	
SUPPORTING ACTIONS & NEEDS		
Intelligent systems supporting operation: The use of satellite positioning and smart, radio-connected intelligent wayside objects as well as the development of a modern train integrity solution will move towards achieving deployment stage and will allow reducing operations costs. They will further facilitate maintenance efforts, improve operational efficiencies and open new functional possibilities for railway network information management and control.		
Using big data to provide **adequate information to customers and train operating companies** to improve their choices (i.e. predictive maintenance, provide services based on customer needs).		

2. Transport electrification

Transport electrification can substantially contribute to breaking transport dependency on oil and decreasing drastically CO_2 as well as emissions of air pollutants such as particles and Nitrogen Oxide. The increasingly decarbonised generation of electricity[36] will provide cleaner electricity to propel electric drivetrains and electric vehicles (EVs) and vessels, while electric vehicles will be able to provide storage services to the grid favouring further penetration of renewables. The development of energy storage technologies and devices remains a cornerstone of a fully electrified transport system well integrated in a clean energy network. Decreasing batteries costs while increasing their energy density and lifetime will speed up electrification of road transport.

The decrease in battery costs has been steep since 2010. Thanks to these advancements, electrification is expected to have an increased impact on the light duty vehicle (LDV) road transport segment over the next decade. The action on "Developing affordable and integrated energy storage solutions" of the Commission Communication on Accelerating Clean Energy Innovation[37] is conceived to contribute to these goals. In the short term (up to 2020), electrification is expected to penetrate primarily road transport, while advancements in battery technologies and deployment of infrastructure will open the door for a greater number of applications in other transport modes with bigger penetration expected on the medium (2030)- to long-term (2050). In the waterborne sector e-ferries trials are already targeting medium distances[38], while the use of cold ironing in harbours will lead to benefits in terms of fuel economy and quality of air[39]. Similarly, aviation electrification can be used in ground operations, while hybridisation of propulsion systems for short range flights might become a reality by 2035[40].

On top of its research and innovation efforts in the field of battery development, the European industrial supply chain will also need to strategically adapt its value chain in order to meet the demand for EV batteries through domestic production, hence fully profiting from transport electrification also in terms of job creation and global competitiveness in this domain[41]. The battery market is expected to grow rapidly and Europe is an important player in providing raw electrochemical materials and production equipment. However, Europe is lagging behind in production capacity and experience in mass production, hampering its ability to rapidly ramp up its capacity and become a leader in the production of the next generation of lithium or post-lithium battery cells.

The deployment of a network of recharging points covering homogeneously the whole EU road network, furthermore, represents another key enabling condition for the uptake of transport electrification. An important step in this direction comes from Member States that, in the framework Directive 2014/94EU on the deployment of alternative fuels infrastructure[42], have to developed and implement their national policy frameworks for the deployment of infrastructure. Further Research and Innovation is needed on innovative form of charging, interoperability of services and profitability of business models.

[36] By 2050 97% of electricity consumed in the EU could be generated from renewable sources. EC Energy Roadmap 2050 (link)
[37] Com (2016) 763 final (link)
[38] Exploring the Potentials of Electrical Waterborne Transport in Europe: The E-ferry Concept (link)
[39] Shore Side Electricity in Europe: Potential and environmental benefits (link)
[40] See ACARE SRIA, especially on commercial flights
[41] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC105010/li-ion_battery_value_chain_and_related_opportunities_for_europe_jrc105010.pdf
[42] Directive 2014/94/EU (link)

2.1. State of the technology development

The achievements in technology development for electric vehicles have been impressive in recent years, important improvements have been made and demand for Electric Vehicles is rising. Electric mobility is developing all over the world, reflecting awareness of the ever increasing problems of providing primary energy and raw materials, of climate change and of the impact of noxious emissions on health. Nonetheless, significant differences exist between the four transport modes considered, addressed in the following paragraphs, together with batteries and infrastructure.

a) Road

Electric mobility is a truly disruptive technology that does not just change the powertrain of the automobile, but also the conditions of its use, e.g. the underlying business and financing models. This may lead to completely new user behaviours and preferences.
Today, around 30 battery-electric vehicle models and 30 plug-in hybrid vehicle models are available to the market. This number may be expected to rapidly grow following recent manufacturer announcements. According to the International Energy Agency, the EU was the world second-largest market with ~500.000 electric vehicles on the road, which a projected strong growth. However, in order to reach full mainstream, further efforts on vehicles, charging infrastructure and system integration are needed
The number of battery-electric and plug-in hybrid vehicle on the road is still small but steadily increasing after vehicle manufactures have launched dedicated models on the market, grid operators installed public charging infrastructures and governments worldwide funded multiple demonstrations and pilots, and created framework conditions, regulations and incentives for purchase and use of electric vehicles.[43]

In addition to that, electric bicycles/ pedelecs are commonplace now[44]. Also, electrification of road vehicles has been extended to delivery vans, light trucks and buses, and prototypes of larger electrified trucks are developed as well.

Electric bus pilots and early fleet projects are growing in Europe and are projected to further grow until 2030[45]. With current battery technology charging electric buses with a real-use range of around 100 km is feasible without compromising the passenger capacity of the bus. On high capacity routes today these buses can offer zero emission at affordable prices. Plug-in hybrids are also viable options using less battery and having a combustion engine offering more route and range flexibility.

Electric urban trucks are emerging today from niche markets. Current energy density of battery packs limits range and load capacity, especially for the short wheel base trucks typically employed in inner cities. Compared to buses, the volumetric energy density of the battery pack is more critical for truck packaging. Battery cell prices as well as the volumetric energy density are rapidly decreasing (faster than expected), to such an extent that urban medium duty full electric trucks will be cost competitive over new diesel trucks with respect to total cost of ownership.

[43] Implementing Agreement Hybrid and Electric Vehicles of the International Energy Agency, Hybrid and Electric Vehicles – The Electric Drive Commutes. Annual Report on 2015, 2016. www.ieahev.org
[44] A massive sales growth in electric bikes sales is observed in the last 10 years, which could contribute to substitute cars for short distances. See: www.cyclingstrategy.eu
[45] Work under the EU funded project ZEeUS on electric buses projects now considers a share of up to 50 percent of electric buses in annual registrations by 2030 possible, based on a survey of operators.

b) Waterborne

Ships use electrical power on board to support service and hotel loads. This includes fans, pumps, compressors, cranes, lighting, heating, electronics and computing. On board electrical loads range from a few hundred kW in smaller cargo vessels to tens of MW in larger ships such as cruise-liners and on board diesel generators are normally used to supply these loads in port. However in order to improve local air quality the use of shore based plug in electrical supplies is increasingly encouraged. Ships are propelled by mechanical and electrical means. Around 2,500 ships in the world are powered by electric propulsion including cruise liners, shuttle tankers, offshore support vessels, Liquefied Natural Gas tankers and ferries.[46] Electric propulsion offers advantages in performance and/or efficiency over traditional mechanical drives which are more popular in vessels that operate over long distances.

Ships driven by electrical means have either an Integrated Full Electrical Propulsion system, a hybrid electric propulsion system or an all-electric 'battery' system. In Integrated Full Electrical Propulsion and hybrid electric propulsion systems the electrical power is generated on board the ship whilst in all-electric systems electricity is generated ashore, although other energy storage systems have been considered. In view of the large batteries needed within all electric vessels substantial shore based charging infrastructure is often required.

Integrated Full Electrical Propulsion systems are commonly found in ships from passenger vessels, Liquefied Natural Gas tankers, shuttle tankers, cruise ships, ferries and offshore support vessels. Typically diesel-generators generate alternating current at constant voltage and constant frequency which is distributed to both service and propulsion systems. Power converters are generally used to control propulsors thrust. All electric battery powered ships are emerging for shorter ferry routes up to 50km.

c) Aviation

The aviation sector can be considered to be in the midst of a pioneering era with regards to electro-mobility. As a result, dramatic and disruptive changes to component/sub-systems technologies coupled with experimentation of Propulsion and Power Systems (PPS) architectures and/or aircraft morphologies are currently taking place[47]. At this point in time, electro-mobility for aircraft only exists in the single/twin-seater categories and typically consists of retrofits of existing conventional designs with reduced payload capability.[48]

Regarding fixed-wing commercial aviation, on-going step-wise development of even a hybrid-electric passenger aircraft appears promising. Irrespective of these difficulties, one of the world's leading commercial aircraft integrators, Airbus Group, has recognised the potential of electro-mobility for aeronautical applications, and has committed resources to the so-called "E-Aircraft Programme", an industry led initiative conceived by Airbus Group in order to pave the way forward in a piece-meal fashion for commercial aircraft to operate with fully-electric propulsion as the ultimate goal.

d) Rail

On busy lines electrification makes most sense economically and from a carbon savings' perspective. On low-density lines today there is no proven cost-efficient solution to replace

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[46] Clarksons Data Base; (link)

[47] For example Zunum project (supported by boeing) http://zunum.aero

[48] Pornet, C., Isikveren, A. T., "Conceptual Design of Hybrid-Electric Transport Aircraft", Progress in Aerospace Sciences, Elsevier, Vol. 79, November 2015, pp. 114-135, doi: 10.1016/j.paerosci.2015.11.002.

diesel-powered trains. Rail has been the first transport mode to introduce emerging technologies of power electronics such as Gate Turn-Off thyristor (GTO) in the past and silicon-based Insulated-Gate Bipolar Transistor (IGBT) 15 years ago. The development of new electric motors has always been and is still at the spearhead of R&D efforts of the railway industry. The first generation of TGV (*Train a Grande Vitesse*, 1981) was using DC (direct-current) motors with a ratio of 2,9 kg/kW.

Nonetheless, when return on investment for electric wiring is not possible due to the frequency and the usage of certain lines, hydrogen and fuel cells can be considered as an alternative. In Northern Germany and in Latvia, train companies are starting to use hydrogen based technologies. However, the application of fuel cells technology in the rail sector poses specific challenges in terms of mechanical and thermal stress, reliability, availability and lifetime.

e) Batteries

Batteries[49] are one of the most important parts of the electric powertrain, as they determine the range, cost and safety of the vehicle system. Since 1990 the specific energy (Wh/kg) of Li-ion cells has increased significantly: the highest gravimetric energy density achieved for Li-ion cells to date amounts to about 235 Wh/kg[50][51]. A typical gravimetric energy density at battery pack level is 140-150 Wh/kg, while a volumetric energy density – which is equally relevant for automotive applications – is 275 Wh/l[52][53]. Even though the theoretical limit of the specific energy of Li-ion cells has not yet been reached, future improvements can rather be expected at the material and battery pack level including wiring, electronic control circuits and conditioning components, as more than 50% of the weight of a battery pack consists of non-active materials[54]. Hence, there is considerable room for automotive-specific battery designs. Even without new chemistries, such designs could also lead to improvements in specific energy and increased manufacturing productivity (output in Wh per unit time).

The high cost of lithium-ion batteries is widely seen as the biggest barrier to mass adoption of EV; others are standardization and manufacturability. With the creation of its gigafactory, Tesla Motors is aiming at economies of scale in mass production of EV batteries[55]. In spite of the many research projects on post-Li-ion batteries which aim at higher energy densities at lower cost, there has not been evidence of a system ready for manufacturing yet. In order to reach the ultimate goal of the EV's autonomy being comparable to the one of a conventional car new chemistries have to be applied, such as Si-based anode, high voltage electrolyte and cathodes or in the longer term Li-S and Li-Air systems[56] that improve cycle life, allow batteries to be charged at high power and to be produced sustainably. In the short term, however, a good compromise between on board capacity and fast charging could deliver similar levels of convenience without burdening the vehicles with the cost and weight of large battery packs.

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[49] The same holds for fuel cells if hydrogen is used for energy storage

[50] M. S. Whittingham, "History, Evolution, and Future Status of Energy Storage", IEEE Proc., 100: 1518-1534 (2012).

[51] A Review of Battery Technologies for Automotive Applications, A joint industry analysis of the technological suitability of different battery technologies for use across various automotive applications in the foreseeable future, EUROBAT, ACEA, JAMA, KAMA, ILA.

[52] A Review of Battery Technologies for Automotive Applications, A joint industry analysis of the technological suitability of different battery technologies for use across various automotive applications in the foreseeable future, EUROBAT, ACEA, JAMA, KAMA, ILA.

[53] Current levels exceed the short-term reference given in the Declaration of Intent of Action 7 of the Integrated SET-Plan, dating from 2014(link)

[54] Moss, R., Tzimas, E., Willis, P., Arendorf, J., Tercero Espinoza, L., 2013. Critical Metals in the Path towards Decarbonisation of the EU Energy Sector. EUR 25994, European Commission, Joint Research Centre, Institute for Energy and Transport, Petten, The Netherlands.

[55] https://www.tesla.com/de_DE/blog/gigafactory

[56] J. Cho, P. G. Bruce et al., Challenges Facing Lithium Batteries and Electrical Double-Layer Capacitors, Angew. Chem. Int. Ed. 2012, 51, 9994 – 10024 and Action 7 of the Integrated SET-Plan

Increased electrification based on battery technology will require stepped up efforts for managing the growing amount of batteries having reached end-of-life for their application in transport. Repurposing and recycling batteries will represent a challenge but also an opportunity for economic and resource savings in future transport and energy storage system.

f) Charging technology infrastructure

The broad deployment of electric vehicles pushes for public charging infrastructures, both for high power (or fast) charging enabling longer distance travels and short recharging times and normal/medium power charging points in public areas, notably in urban dwellings where electric vehicle users or owners may not have access to a private garage or parking place, but need to regularly perform overnight charging.

Directive 2014/94/EU on the deployment of alternative fuels infrastructure[57] specifies at least Type 2 connectors according to EN 69196-2 for normal and high power Alternating Current (AC) charging and at least the Combined Charging System (CCS) according to EN 62196-3 for high power Direct Current (DC) Charging.

Research and innovation needs in this area relate particularly to resonant wireless charging. It is another quite promising and practical technology with efficiency around 90% from the mains to the battery (plate to plate efficiency can reach 98%). The limitations on the maximum power transmissible and more specifically the limit on power density are likely to restrict the use of wireless charging to normal/medium power charging. The technology has been presented to provide continuous charging on roads, including highways when the vehicle is in motion[58] Further efforts are needed to understand real-life performance from demonstration projects and approaches to cost reduction for the related infrastructure, which appears to be prohibitive. Further work is needed to improve technological maturity and study conditions for a wide to spread as a basic element of the city infrastructure, especially for bus station/stop applications[59]. This work is needed to also inform ongoing standardisation work in the area. This charging technology is equally interesting for airport platform vehicles.

2.2. Focus areas for action

The scope of the activities in this area of transport electrification should take into account both advanced power-train technologies and new vehicles architectures, weight reduction, improved aerodynamics and rolling resistance and component development for alternative fuel vehicles.

Concerning new forms of energy, the interfaces between the vehicles and the recharging infrastructure also need to be addressed as well as users' needs.

The proposed approach takes into account and brings forward the achievements obtained in the framework of the European Green Vehicle Initiative (EGVI) and encourages multi-

[57] Directive 2014/94/EU

[58] A. Gilbert: Wireless Charging: The future of Electric car. In: G. Meyer (Ed.), Advanced Microsystems for Automotive Applications 2012, Springer 2012, Berlin.

[59] The development of European standards on inductive charging is part of the European Commission mandate (M533) accepted by the CEN/CENELEC in 2015.

sectorial/multi-disciplinary research and innovation activities on new materials, advanced production systems, ICT, particularly in fields such as advanced energy storage systems and interfaces between vehicles and recharging infrastructures, vehicle design and manufacturing.

A SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of Europe's international position by transport modes is outlined below.

a) Electric road transport

Strengths:

- Leadership in vehicle, electric and fuel cell components / architecture engineering
- Leading global players in LDV and HDV industries and their supply chains
- Know-how in science, engineering, system integration of batteries and fuels cells
- High reliability of the electricity grid for most Member States
- High-quality of public transport services
- Strong portfolio of high quality vehicles (1st generation[60])
- Fast-growing share of renewable energy sources

Weaknesses:

- Not yet fully convergent long-term vision of the automotive industry
- Insufficient convergence of views in governments and industry about long term powertrain choices
- Resistance of customers to change
- Diversity of electric vehicle portfolio, ranges, prices and marketing has just started
- Limited automotive battery and fuel cells technologies manufacturing
- Delay in adapting street infrastructure and urban planning constraints.

Opportunities:

- Widely recognised need to address air quality and noise challenges
- Savings on fuel imports could improve EU trade balance
- Electrification is a key enabler for a low carbon energy future
- Electric mobility sector is still evolving so EU companies can still play a strong part in shaping it
- Enabling policy measures (such as real driving Emissions and CO2 standards post 2020)

Threats:

- Rapid deployment and manufacturing capacity of zero or low emission vehicles in other key markets
- Imports enter EU value chains for electric mobility

b) Electric aviation transport

Strengths:

- Competencies in R&D and exploitation in aviation, batteries and energy storage management
- Trans domains technology leads to synergies

[60] 1st generation refers to powertrains, not optimised for the use of electricity, while the 2nd generation powertrains are conceived with this consideration taken into account.

Weaknesses:

- Low Technology Readiness Levels at the moment, especially in HTS
- Lack of interdisciplinary competences (system engineering)
- Lack of standards and regulations for electric aviation

Opportunities:

- General objectives of pollution reduction, CO_2, NO_x, noise
- New airports further away from the cities (new market for small e-aircraft landing in or near the cities)

Threats:

- Competition, mainly from US on avionics and batteries
- Lack of real industrial agility among supply chain components

c) Electric waterborne transport

Strengths:

- EU Industry leads in marine equipment, passenger ship building and marine electrical technologies
- EU public tuned to and sympathetic to environmental issues including maritime
- Increased public demand to improve the environmental performance of shipping.
- EU industry is strong at green technology and benefits from advances in environmental standards

Weaknesses:

- EU battery R&D is weak but improving
- Electric Storage Systems (ESS) technologies are not being researched sufficiently well
- Due to higher labour and production costs, European ship building is focused on high technology vessels and not the large volumes of merchant ships which represent the majority of the world fleet
- Oil prices are currently low and this is a disincentive to invest in new technology

Opportunities:

- Energy Efficiency Design Index provides credit for use of innovative technologies.
- Important patents in electro-tech rest in the EU
- Large EU fleet (nearly 8000 vessels and 40% of the world) and a major trading area
- Large number of ferries many on short route.
- Cruise ships are early technology adopters and these are almost all European.
- Increased take up of Liquefied Natural Gas (LNG) facilitates fuel cell applications.
- Fuel cell for power applications now at levels suitable for marine propulsion.
- Fast development of battery technology being driven by the automotive sector

Threats:

- Oil prices remain low
- Intellectual property is lost outside of Europe
- Associated employment is outside of Europe
- Conservative industry – likely to resist change, the International Maritime Organisation does not support the measures
- Low political priority within Europe
- Class and safety approval is too heavy
- No first adopter to take up radically new technology commercially
- Technology is not transferable from automotive to marine
- Fuel cell's technology cannot be made robust and reliable

d) Electric rail transport

Strengths:

- EU global leadership in rail research and innovation
- Large electrified network
- Holistic approach of the railway system innovation by researchers and industry

Weaknesses:

- Last miles solutions
- Electrification of secondary network
- Limited capacities for freight
- Variety of standards among EU countries
- Small scale level of project cases, low return on investment

Opportunities:

- Great contributor to decarbonisation of transport
- General objectives of pollution reduction, CO_2, NO_x, noise in cities and territories
- Immediate benefit for railway electrification utilisation
- New propulsion energy

Threats:

- Competition, with manufacturers from other regions
- Competition with other transport modes
- Limited financing capacity of public investment for infrastructure
- Failing to meet customer satisfaction and serve users' needs

2.3. Short-term research and innovation actions

2.3.1. Electric road transport

The following tables highlight the contribution of research and innovation actions to enable and deliver road transport electrification.

	Deployment	**Product Development and Operating Models**	**RESEARCH AND INNOVATION**
Enable & Deliver 2020	Increase market share for electric passenger cars, even higher in the urban environment (bikes, buses, vans)	As far as general purpose vehicles are concerned, cost reductions will enlarge the customer base. At the same time, new vehicles will cater for emerging business models based on total-cost-of-ownership considerations, e.g. fleet applications, car sharing, delivery vans	*Initiatives listed in the roadmap of ERTRAC / EPoSS / Smart Grids*

Action 1

Promote a 400km+ range electric passenger car that meets customer expectations

Action 2

Progress and demonstration in urban bus electrification
R&I program on energy storage systems, thermal comfort as well as low energy air-conditioning. KPI is a Carry all energy for a one day trip on the bus and still stay within cost targets

Action 3

Public and commercial procurement of EVs
Promote the market and create awareness of electric vehicles' maturity and a second hand market of electric vehicles in line with revision of Directive 2009/33/EC

Action 4

Certification of electric vehicles performance
Better comparability of EV types, also for commercial use

Action 5

Development of small and light smart electric vehicles: Components and concepts enabling radical reduction of energy consumption

Action 6

Support local production of batteries, components and electric vehicles
Awareness actions for smart specialization and governance in anticipation of value chain disruptions due to shift from conventional to electrified vehicles

2.3.2. Electric aviation transport

The following tables highlight the contribution of research and innovation actions to enable and deliver electrification in aviation.

	Commercial Aviation (50-70 seats) and equivalent cargo < 7 tons)	Commercial Aviation (>70 seats and equivalent cargo >7 tons)	Personal Aviation	Drones	Airport Environment
Enable & Deliver **2020**	Electrification of Auxiliary Power Unit (APU) and of all non propulsive systems Normal conducting; Emergence of adaptive structure (flow control); Decentralised architecture; Standards for e-planes	Engagement on low TRL for High Temperature Superconductor, Demo HTS	Substantial increase in hybridisation; First flights short range	Substantial increase in hybridisation	Electrification of services; All support vehicles electrified; Airports equipped for charging auxiliaries

Action 1

Electric Aircraft Design
Introduction of new design methodologies to reach 50% hybridisation

Action 2

Zero emission and very low noise airports: reduction of 80% for NOx and 50% for CO2 emissions of support vehicles and 5 dB less noisy airports compared to 2000 (FlghtPath 2050)°

Action 3

Ensure a specialised interdisciplinary work force
Development of skills and competences in system engineering (high level education), technologies (engineers, technicians, employees: integration, design, exploitation and maintenance, etc), and security/safety aspects

Action 4

To decrease cost, and increase product development speed
Development of regulations (e.g. integration of the electrification in the airport fees/taxes) and standards for electric planes

2.3.3. Electric waterborne transport

The following tables highlight the contribution of research and innovation actions to enable and deliver electrification in waterborne.

	EU general waterborne transport	International shipping	Small vessels
Enable & Deliver 2020	The majority of shipping equipped with standard connecters to facilitate cold ironing. All EU trading ports to offer electric plug in for ships allowing the ships engines to be switched off. Hybrid electric systems are increasingly deployed, including on inland waterways and have significantly larger battery capacity in comparison to 2016. Fully electric vessels deployed for urban waterborne transport.	All EU trading ports to offer electric plug in for ships when docked so as to supply electricity directly to the ship allowing ships engines to be switched off. Increasingly ships transiting European ports are equipped to benefit from shore side power.	Quantify emissions from small boats across the EU and globally. Prioritise actions required for small boats to meet the emission standards applicable to non-road mobile machinery. Increasing sales of electrically propelled boats.

Action 1

Raise public awareness of benefits of electrified vessels
Inform public about the dependency on shipping, the environmental and health benefits of moving towards more electric ships

Action 2

Deploy new materials and technologies. Develop new protection methods with respect to some Electric Storage System technologies e.g. Lithium, light weight, higher strength materials, improved electro-chemistry knowledge: batteries, improved energy densities

Action 3

Support education and training
Develop new skills to feed into new industries such as in battery technologies, other ESS technologies, Appreciation of EU strategists of ‘moving technology’ and ‘operational changes’ together.

2.3.4. Electric rail transport

The Transport White Paper identifies two segments of the transport market where it would particularly welcome to increase the share for rail. These are long-distance overland freight, and medium-distance passenger travel, notably through the expansion of high-speed rail. The following tables highlight the contribution of research and innovation actions to enable and deliver electrification in rail.

	Climate Change & Emissions	**Energy consumption**	**RESEARCH AND INNOVATION**	**Noise and vibrations**
Enable & Deliver 2020	Further reduction of specific average CO2 emissions from train operations		*Reference to the ERRAC Roadmap on the Greening of Surface Transport 2020*	
Action 1	**Increase the potential for utilisation of electric motorization** Electrification of secondary network requires implementation of adequate infrastructure along most utilised lines			
Action 2	**Intensify electric freight rail transportation** Maximise the ton-km transported by electric rail			
Action 3	**Harmonise energy characteristics for rails in EU**			

2.4. Outlook for research and innovation actions until 2050

2.4.1. Electric road transport

	Deployment	Product Development and Operating Models	Research and Innovation
Enable & Deliver 2030	Significant market share for electric vehicles, in particular battery-electric, and the small vehicle segment	Operating models supported in place by availability of energy storage systems and infrastructures meeting user demand for clean, economic and convenient mobility	Reaching synergies between various technology fields (electrification, automation, connectivity, energy efficiency, light weight, charging etc.)
Action 7	**Further development of small and light smart electric vehicles:** To be supported by connectivity and automation, new mobility, car sharing service and business models especially for urban usage		
Action 8	**Demonstration of electrified road systems for HDVs** Compensate limited range of battery-electric heavy duty vehicles through charging en-route. Cross border demonstration and piloting of electrified road systems based on wired or wireless charging or battery swapping.		
Action 9			**Develop electro-chemical systems for future high-density EV batteries:** Gather unique know-how for potential European leadership in battery technology production
Enable & Deliver 2050	Phasing out of conventional fuelled cars	Different world of operation with electric vehicles seamlessly integrated into the transport and mobility systems	The use of big data, artificial intelligence, quantum computing

2.4.2. Electric aviation transport

	Commercial Aviation (50-70 seats) and equivalent cargo < 7 tons)	**Commercial Aviation (>70 seats and equivalent cargo >7 tons)**	**Personal Aviation**	**Drones**	**Airport Environment**
Enable & Deliver **2030**	At least 30% Hybridisation for power; At least 10% hybridisation for stored energy[61] Normal conducting; Implementation of distribution propulsion and /or boundary layer injection technologies	Electrification of Auxiliary Power Unit (APU) and of all non propulsive systems HTS at TRL 6, components using HTS	Full electric aircrafts Medium range flights (200kms)	Full electric aircrafts	Mild electrification Introduction of induction charging for aircrafts All airports: Infrastructure available for charging small planes (<70 seats)
Action 5	**Energy storage systems improvement** Continuous effort on R&D, industrialisation and manufacturing processes on batteries and hybrid energy storage .				
Action 6	**To achieve maturity in High Temperature Superconductors** Continuous effort on R&D on HTS, including machines, cooling and wiring				
Enable & Deliver **2050+**	Full electric aircrafts, operational modes for very short haul; Substantial increase in hybridisation and storage capacity Full High Temperature Super conducting (HTS); Fully operating distribution propulsion and /or boundary layer injection technologies and adapted structures	At least 30% Hybridisation of power At least 10% hybridisation of stored energy Beginning of HTS in retrofit	Full electric flights more than 500kms	Full electric aircrafts	Full electrification Wide scale induction charging All airports: Infrastructure available for charging all planes

[61] The European industry together with research establishments and academia, aim to demonstrate a hybrid-electric propelled aircraft, below 100 seats, by 2030, see 'Airbus Group and Siemens Sign Long-Term Cooperation Agreement in the Field of Hybrid Electric Propulsion Systems', Press release, 7/04/2016

2.4.3. Electric waterborne transport

	EU general waterborne transport	International shipping	Small vessels
Enable & Deliver 2030	Expansion of ESS (Electric Storage System) ships in EU territorial waters. Ships operate using ESS technologies on an increasing number of routes. Vessel transiting between ports in the range of 20-30 miles distance should be able to operate on ESS alone. Ports to be able to offer recharging facilities during a normal turn-around (3-4 hours).	Ships arriving from outside EU operate on ESS when entering and leaving port. Intercontinental ships use ESS to reduce emissions when entering and leaving port and use cold ironing when alongside. Fuel cell technology has been demonstrated at a scale appropriate for intercontinental shipping and cruise liners.	Promote technology development which will enable all small boats to meet the emission standards applicable to inland vessels within the non road mobile machinery regulations. Electric or fuel cell propulsion represents a significant proportion of the small boat market.
Action 4	**Innovative financing tools** Collective investment (private, public, community) to fund change, Infrastructure impact such as grid – spread costs across the EU		
Action 5	**New Business Models** Battery roll-on/roll-off container technologies so as to swap to battery when in port		
Enable & Deliver 2050	ESS ships using either batteries or fuel cells are the majority of those operating in EU territorial waters. Vessel transiting with sailing times of 48 hours (type 500 miles) should be able to operate on ESS alone. Ports to be able to offer suitable recharging facilities.	All ships arriving from outside EU should operate on ESS when entering EU emissions free zones Intercontinental ships can use ESS to reduce emissions when entering and leaving EU emissions free zones (to be defined) Marine diesel engines are fitted within a minority of new build shipping. Other technical options such as Hydrogen and Fuel Cells are also emerging.	Drastic reduction of diesel engines in all boats. European emission standards for small boats are increasingly adopted globally.

2.4.4. Electric rail transport

	Climate Change & Emissions	**Energy consumption**	**RESEARCH AND INNOVATION**	**Noise and vibrations**
Enable & Deliver 2030	Drastic reduction of specific average CO2 emissions from train operation With current trends and policies in place, the European railways is expected to see by 2030 a decline of more than 20% of CO2 emission, compared to 2005, despite growing activity. A significant reduction of total exhaust emissions of NOx and PM2.5 is also expected[62]	Substantial reduction of specific final energy consumption from train operation	*See ERRAC Roadmap on the Greening of Surface Transport 2030*	
Action 4	**Development of new motorisation** Research and innovation on new engines and new power; transfer technologies from other domains (e.g. batteries or fuel cell) and develop specific knowledge			
Action 5	**Intensify electric freight rail transportation** Maximize the ton-km transported by electric rail			
Action 6	**Develop light vehicles** Increase the electric rail modal share in small and medium size cities (passengers and freight)			
Action 7	**Develop intermodal hubs in cities** Develop charging stations for all vehicles (from bikes to busses) at rail stations/terminals			
Action 8	**Minimize the losses in the electric railway infrastructure** Continuous effort on R&D, industrialisation and manufacturing processes to smart power grids for rail			
Enable & Deliver 2050+	R&I to enable carbon-free train operation Zero emission of nitrogen oxides (NO_x) and particulate matter (PM_{10})	Halving their specific final energy consumption from train operation by 2050	*See ERRAC Roadmap on the Greening of Surface Transport 2050*	Noise and vibrations no longer being considered an issue for the railways

[62] EU Reference Scenario 2016 (link)

3. Vehicle design and manufacturing

Transport vehicle design, development and manufacturing (VDM) is a collaborative, integrated and highly complex set of processes and tools that considers the whole vehicle life cycle and is a key element for the competitiveness of EU transport industry and provides a key contribution to circular economy. Performance of the vehicle, energy storage, powertrain, environmental requirements connectivity, automation, safety, security, passenger comfort and regulatory issues are all part of VDM, which should also help reduce emissions of noise and air pollution.

Continuous research and innovation as well as organizational improvements aim towards successful marketable transport vehicles with shorter development time and time-to-market. The global trend is towards seamless integration of digital and physical vehicle design and manufacturing processes, tools and infrastructures. Europe is world leader in transport design and manufacturing. The automotive, rail, aeronautics and shipbuilding sectors had a turnover of above € 350 billion in 2015 (€ 140[63], 120[64] and 91[65] billion respectively) and account for more than 3.6 million highly qualified jobs. Research and innovation in this area aims at reinforcing the competitive edge of the European transport industry in a global context.

3.1 State of the technology development

This chapter is complementary to VDM issues addressed in the other chapters.

a) Road

The automotive industry is in the midst of a new era of personal transportation revolution. Pilot connected and automated cars are moving from research labs to the streets. Design and manufacturing of hybrid and electric vehicles with self-driving capabilities, infotainment systems and applications, remote diagnostics and vehicle-to vehicle communication is cross-platform and covers different sectors and disciplines. In the automotive sector the main trends of VDM are:

- decrease in development time - development of advanced design tools
- modular solutions
- more integration in the supply chain
- regulation-driven new technologies
- growing complexities of customized vehicles
- focus on research, development and innovations

Development time of new car models averages about 25 months today but is expected to be reduced to levels below 20 months over the next decade. Suppliers must be involved at the very early stage of vehicle design process in order to eliminate the inefficiencies along the whole value chain and achieve economy of scale. Advanced design tools and Product Lifecycle Management (PLM) software play a key role towards decreasing development and integration time as well as the risk of quality issues of the complex mechanical, electrical and software systems of modern cars.

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[63] European Automobile Manufacturers Association, ACEA, http://www.acea.be/statistics/tag/category/key-figures
[64] Aerospace and Defence Industries Association of Europe, ASD Facts-Figures, 2015 http://www.asd-europe.org/fileadmin/user_upload/ASD_F_F2015_web.pdf
[65] Shipyards' and Maritime Equipment Association, SEA Europe, http://www.seaeurope.eu

Modularity contributes to overcome risks at intermediate Technology Readiness Levels (TRLs) and facilitates progress via the integration of physical and digital resources. There is need for IT solutions that allow safe and efficient exchange of data between different members of the value chain.

Growing complexities of customized vehicles will require a novel approach to the assembly process based on global platforms. Research on standardization (including data standardization), will be key towards allowing modular manufacturing processes.

b) Waterborne

Europe's 300 shipyards provide employment for more than 500,000 workers, generating average revenues of about €30-40bn a year[66]. While China, Japan and South Korea now have more than 80% of the shipbuilding market share, Europe is maintaining its leadership in the high-value cruise sector with more than 90% order-book.

The factors affecting the shipbuilding industry can be divided in two groups: macro factors (world seaborne trade, oil prices, economic, and political stability) and market factors (subsidies by the government, scrapping of old vessels, charter rates, vessels on order)[67]. The main trends in shipbuilding are:

- integration between digital design and digital manufacturing
- manufacturing and production planning
- new powertrain architectures
- temporary power source

Shipyard's competitiveness today is very much dependent on the level of production management together with Design-for-Manufacturing and Design-for-Assembly capabilities. In both cases, digital design and digital manufacturing can further reduce cost, enhance quality and significantly reduce operational delays and reworks.

The vast majority of modern vessels rely on some form of diesel engine for their prime propulsive power. However, the advantage of a hybrid power plant on lower activity levels is to help reduce emissions and energy consumption. Another alternative is to use batteries as a temporary power source, resulting in zero emission cruising. A combination of diesel engine, generators and batteries allows the system to supply the required power more efficiently than a conventional diesel system.

c) Aviation

From European perspective, aviation design and manufacturing is above all about maintaining and extending industrial leadership. ACARE has developed a Strategic Research and Innovation Agenda[68] (SRIA) to meet the challenging goals set by Flightpath 2050[69]. Innovation in aviation is key to tomorrow's mobility and prosperity as well as environmental and energy challenges. The main trends in aviation are:

- fierce international competition
- new business models
- energy and environmental performance

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[66] CESA, Community of European Shipyards Association, http://www.cesa-shipbuilding.org/about_the_industry
[67] Global Competition in Shipbuilding: Trends and Challenges for Europe, Rima Mickeviciene, InTech, 2011.
[68] ACARE, Delivering Europe's vision for aviation, Strategic Research and Innovation Agenda – 2017 update, Volume 1.
[69] FlighPath2050, http://ec.europa.eu/transport/sites/transport/files/modes/air/doc/flightpath2050.pdf

- shorter cycles for technology integration
- research and innovation support and investment proportional to the goals and global leadership.

The aviation sector continues to grow and aircraft orders and deliveries for major commercial aircraft manufacturers are at all-time high. The sustained growth in aviation drives competition between traditional (i.e. USA) and emerging nations, such as Brazil, Canada, China, India, the Gulf States and Russia. Even though the global aviation market is increasing in size, Europe must preserve its pre-eminent position to ensure the continued success and economic contribution of its aviation industry by investing continuously and heavily in key enabling innovation, research and technology supported by adequate policies and frameworks. European aviation needs to build its competiveness across all horizontal industrialisation aspects: standardisation, specialisation, collaboration, automation and agility.

Costs of entry to the sector are reduced with greater use of digital and data-based business models as well as advanced conventional and disruptive manufacturing technologies. The digital, zero waste, and energy-neutral factories will use data-driven manufacturing systems to ensure high productivity, permit rapid new technology implementation, and enable product and rate flexibility through supply chain integration. Energy and environmental performance in aviation may require ground-breaking changes in future air-vehicle concepts for both the airframe and the propulsion. New approaches for design and manufacturing and especially system integration are necessary. Electric and hybrid propulsion for aviation moving towards eliminating emissions is highly challenging. It will require breakthrough technologies and is expected by the mid of this century.

In the medium to long-term, the development of an electric or a hybrid design will open up new challenges. Electric propulsion for transport aircrafts requires a rethinking of aircraft configuration. The market demands ever-shorter cycles for technology integration with, at the same time, aggressive pricing. Supporting policies must be developed to include emerging cross-sectorial enablers such as digitalisation, big data and Industry 4.0. The mechanisms for this support must build on best current practice, target the full innovation value chain, and recognise the unique lead times of technology maturation, and the scale and complexity of future technologies.

3.2. Focus areas for action

1. Enable shorter vehicle design, development and manufacturing cycles.

Transport vehicles have become very complex mechatronic systems (e.g. more than 2 million mechanical and electrical parts and more than 7 million lines of software code in a modern aircraft or large passenger ship). Multidisciplinary interactions between mechanical, electrical and software systems often give rise to difficulties and uncertainties in the final integration and manufacturing, which in turn result to unexpected costs and delays. Product complexity is multidimensional and consists of product, process, organizational, market and use complexity. It is the ultimate goal of VDM to master this complexity and produce competitive, green, safe and comfortable transport vehicles. An organised methodology towards mastering VDM complexity is partly addressed by Collaborative Engineering Environment (CEE) - toolboxes that allow the creation, storage and retrieval of information along the whole VDM process. Significantly advancing further such toolboxes, along with better understanding of the underlying science and technologies, specific for the transport vehicle applications, has to be encouraged.

2. Enable new vehicle concepts, business models and modular vehicle architectures.

VDM aims at contributing towards new transport business models that will respond to increased passenger demand, congestion (especially in road and air-traffic), autonomy and modularity. All these objectives cannot be achieved unless VDM processes and tools are further advanced towards enabling much shorter vehicle design, development and manufacturing cycles. Entrepreneurship and access to financing are critical elements that the European Union has considered already in other complementary actions (see the Governance chapter).

3. Reduce the environmental impact and allow for recycling and/or remanufacturing

Over the last fifty years, design and manufacturing of transport vehicles has followed an evolutionary path. Yet, design and manufacturing improvements in aircrafts and cars powered by internal combustion engines, have slashed the fuel burn and emissions per passenger km by more than 80%[70] [71][72], increased safety and comfort and allowed for new vehicle categories that respond to operational profiles of new customer needs. While there is still room for further improvements and higher fuel-burn gains, many of the technologies installed on-board transport vehicles have reached their maximum potential. Today, the evolutionary path of vehicle design and manufacturing is disrupted by the high degree of electrification, digitalisation and automation.

In the process of decreasing the emissions of transport, impacts of manufacturing become increasingly relevant. Recycling and remanufacturing can bring high potential in terms of resource savings, especially for high-technological components rich in Critical Raw Materials[73].

Research and innovation actions are grouped in three main strands and are summarised in the table below.

A SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of Europe's international position in Vehicle design and manufacturing (VDM) is outlined below.

Strengths:

- Leadership in vehicle architectures, components and assembly; as well as in supply chain management;
- Leadership in Collaborative Engineering Environments platforms (e.g.: SIEMENS, DASSAULT SYSTEMS, ESI); as well as engineering & system integration;
- European financial instruments and EU funding schemes for SMEs that will allow development and deployment of technology;
- Positive signs for European entrepreneurship – translating European funded project results to technologies for transport related products (e.g. ultrahaptic, sensors, advanced materials).

[70] Alan H. Epstein, A technical vision of Commercial Air-Transportation, Innovation for Sustainable Aviation in a Global Environment, 6th European Aerodays, 2012, p. 366-369
[71] http://www.atag.org/facts-and-figures.html
[72] https://www.epa.gov/air-pollution-transportation/accomplishments-and-success-air-pollution-transportation
[73]COM(2014) 297 (link)

Weaknesses:

- Synergies between transport sectors as well as with other disciplines (i.e. defence, space, electronics) are not adequately exploited;
- Despite efforts at EU and National level, "valley of death" Technology Readiness Level are still not adequately addressed;
- Difficulty to translate innovative concepts in transport products and/or services;
- Regulatory issues are still considered cumbersome and lengthy to transport industries; Expansion of transport infrastructures (e.g.: airports) finds critical opposition from communities.

Opportunities:

- Steady growth (2-6%) in most segments of commercial transport vehicles;
- Results obtained by large-scale demonstration activities in EU-funded research programs are expected to contribute in the coming years;
- European governments, national authorities and industries make coherent plans (see Governance chapter)
- Research and innovation has the potential to offer significant contributions to safe operations in all-weather conditions;

Threats:

- Increased global competition in all transport modes from Asian countries;
- International consolidations, takeovers, mergers and acquisitions in the transport industry may result in loss of European Intellectual Property Rights (KUKA, AIXTRON);
- Non-equal level playing field – government funding, tax credits and dual use research is competing with private sector;
- Geographic fragmentation of the supply chain in Europe and globally;
- Security and disruption of the supply chain;
- International trade wars, protectionism and other intra-European uncertainties
- Long-term European leadership in internal combustion engines in automotive and conventional propulsion systems in waterborne and aviation may delay the introduction and investments in new technologies;
- Cybersecurity will be a critical issue in the coming years – vehicle design has to embed such requirements.

3.3. Short-term research and innovation actions

Research and innovation actions in the area of vehicle design and manufacturing are presented in a way to address all transport modes, although significant differences exist across modes. Research and innovation actions are proposed in relation to the following impacts:
- substantially contribute to the EU transport industry competitiveness by enabling shorter vehicle design, development and manufacturing cycles by 2025, compared to the present state-of-the-art;
- contribute towards substantially reduced transport lifecycle environmental impact. High gains in lifecycle CO2 emissions are expected not only from the introduction of electrification and/or advanced fuels but also from the system integration, new manufacturing processes and the disposal of transport vehicles;

- support the development of future business models. In the coming decades, new business and transport vehicles will fill niche markets and needs (e.g.: autonomy, modularity, low supersonic, flying and amphibious vehicles, etc.).

Enable & Deliver 2020	Enable shorter vehicle design, development and manufacturing cycles	Enable new vehicle concepts, business models and modular vehicle architectures	Reduce the environmental impact and allow for higher recycling and/or remanufacturing
Action 1	Enable advances in inter and multidisciplinary VDM processes and tools. Accelerate Design for Manufacturing and Operations with industrial pilot cases and participation of the extended enterprise.		
Action 2	Embed digitalisation, big data and cybersecurity in the design and manufacturing of next generation of transport vehicles.		
Action 3	Promote design for safe operations in all-weather conditions.		
Action 4	Accelerate the development of Performance-based Standards and Certification processes for sub-systems and vehicles and promote International Cooperation.		
Action 5	Plan and develop European Strategic Research & Testing Infrastructures for future needs.		
Action 6	Integrate Research & Innovation results and support the demonstration of high-risk disruptive technologies. Support exploratory research on new business models and services.		
Action 7	Explore Big Data analysis, Artificial Intelligence and other methods towards linking evolutionary design and operations.		
Action 8	Deliver passenger-centric modular design transport vehicles.		

3.4. Outlook for research and innovation actions until 2030

Enable & Deliver 2030	Enable shorter vehicle design, development and manufacturing cycles	Enable new vehicle concepts, business models and modular vehicle architectures	Reduce the environmental impact and allow for higher recycling and/or remanufacturing
Action 9	Maintain leadership in Vehicle Design and Manufacturing with digital infrastructures across the supply chain that can automatically adapt to demand.		
Action 10	Maintain and extend leadership in merging physical and digital in transport vehicle design, manufacturing, operations and regulations and their seamless integration.		
2050			
Action 11	Leadership in substantially reducing the environmental footprint from transport vehicle manufacturing and transport operations with focus also on remanufacturing and waste reuse/recycling .		
Action 12	Leadership in innovative transport inter-modal integration and business models that will respond to the expected passenger growth in 2050 and beyond.		

4. Low-emission alternative energy for transport

While battery-electric and hydrogen fuel cell powertrains are becoming viable options for many vehicles, aviation, waterborne transport and certain road heavy duty vehicles (HDV) are likely to continue relying largely on combustion engines and liquid fuels for the next decades. For these modes, as indicated in the Communication[74] “A European Strategy for Low-Emission Mobility” the further development and deployment of low-emission alternative energy[75] is needed. A greater use of renewable energy sources for transport together with other measures to increase the transport system's energy efficiency will thus be essential for decarbonising transport in the short and mid-term together with reducing pollutant emissions especially from particles and nitrogen oxides.

Increasing the share of **alternative low-emission** energy poses a number of technical and environmental challenges in terms of energy production[76] and distribution and in terms of transport sector applications. As regards the development of new generations of powertrains, research and innovation efforts should be focused on real step changes for technologies that allow greater and more efficient use of alternative energies with the aim of reducing greenhouse gases and other pollutant emissions. For energy production, research and innovation efforts should focus on novel low-emission alternative energies with much lower GHG emissions, based on renewable and sustainable sources.

Increased research and innovation on renewable alternative energies for transport will contribute to the objectives established in the Commission Directive 's proposal[77] "on the promotion of the use of energy from renewable sources" (recast) and the Commission's Communication[78] "Accelerating Clean Energy Innovation".

Biofuels currently represent the main alternative to fossil fuels[79] in internal combustion engines in terms of volume. This poses resource allocation issues as today's biofuels rely on limited feedstock. Biofuels are largely compatible with standard engines and distribution installations/infrastructure currently used for conventional fuels. This compatibility extends also to advanced[80] drop-in biofuels, which can replace fossil fuels either in pure form or in blends including fuels used in aviation. Food and feed crop-based biofuels have a limited role in decarbonising our society if indirect land use change effects are taken into account. Research and innovation efforts should therefore concentrate on advanced biofuels which today are significantly more costly than conventional fuels and first generation biofuels (produced from food or feed crops). Their broad market up-take is hampered by this cost barrier. Biofuels are still today limited to road transport fleets.

With a preference for drop-in fungible fuels and therefore capable of serving both the current fleet and future hybridised LDV, future research and innovation efforts should focus on an increased, more efficient production and use of advanced biofuels, with a prime focus on aviation, shipping and HDVs, taking into consideration the availability of raw materials and the progress in technology and costs. Moreover, further work is required to assess the

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[74] "A European Strategy for low-emission mobility", COM(2016) 501 final; (link)
[75] Such as, (bio)methane either pure or blended with natural gas in the forms of compressed natural gas (CNG) and liquefied natural gas (LNG), liquified petroleum gas (LPG) blended with bio LPG, synthetic paraffinic fuels, mainly produced from renewable sources, biofuels (alcohols and ethers and esters) and advanced biofuels
[76] Covered especially by the Strategic Energy Technology (SET-) Plan (https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan)
[77] COM(2016) 767 final
[78] COM(2016) 763 final
[79] 5,6% of the energy used in transport in 2014 was from renewable sources, almost all was represented by biofuels.
[80] not produced from food or feed crops but using in particular waste and residues together with efficient conversion technologies

sustainability of feedstock production for advanced biofuels, and their performance in reducing emissions.

In addition to their use in LDVs, the applicability of advanced biofuels has already been well-proven for aviation - with some pathways already certified for blending up to 50% - or heavy duty vehicles. A faster transition towards an enlarged market can be achieved if the economies of scale would lead to significant cost reductions of the advanced biofuels[81].

In aviation, whilst development of radical new designs of aircraft and aviation powertrains is currently on-going, it will take many years for such efforts to reach fruition, with liquid fuels remaining the only option for the sector in the meantime. Drop-in solutions, such as renewable synthetic paraffinic kerosene (SPK), increasing the number of certified pathways and ensuring the development of sustainable and resource-efficient alternative energies will be pivotal in such a context. Such decarbonisation efforts will have to be finally considered from a holistic perspective in association to other measures such as improved air operations or advanced aircraft/airport technology and systems.

Further progress in the HDV sector will imply the deployment of commercially mature engines[82] making a greater use of this renewable fuel without requesting the development of new dedicated engines[83].

Natural gas blended with biomethane (bioLNG) is seen as a short and mid-term substitute to diesel and marine fuels in both the HDV and marine sectors. In addition, synthetic paraffinic fuels from renewable sources could also be an alternative to conventional liquid fuels in the mid-term. Whilst engine technologies capable of making greater use of these fuels[84] in road transport are considered already sufficiently mature and commercially available, their use is not widespread due to a lack of dedicated infrastructure. From an research and innovation point of view, issues such as greater efficiencies, further reduction of pollutants and unburnt methane emissions ("methane slip"), still require attention. In the waterborne sector the progressive deployment of infrastructure for alternative fuels will allow the emergence of dedicated engines (e.g. liquified natural gas blended with biomethane or methanol blended with biomethane); research and innovation efforts in this case will need to focus on increased efficiency of these engines, sustainable and resource efficient fuel production, whilst addressing boil-off emissions from the LNG tanks and methane slip.

Liquefied Petroleum Gas (LPG)[85] blended with bioLPG in the highest possible percentage is another mature alternative fuel, used in LDVs, which could improve the environmental performance of LPG vehicles.

Hydrogen, after an initial test and demonstration stage in internal combustion engines, is now only considered as a viable alternative fuel when used in fuel cell electric powertrains. Hydrogen is increasingly seen as a suitable storage for excess electricity generated by wind and solar power. Thus it is likely to become more widely available, also as a clean fuel for

[81] Under the Strategic Energy Technology plan, agreed Strategic Targets in Renewable Fuels for Sustainable Transport will accelerate the up-take of advanced biofuels (https://setis.ec.europa.eu/system/files/integrated_set-plan/declaration_action8_renewablefuels_bioenergy.pdf)
[82] In HDV DME and ED95 are commercially available products awaiting the roll out of infrastructure. Further work in this area concentrates on improved efficiency, reduced noxious emissions and lowering cost.
[83] Such shift, however, would need to be supported by the deployment of distribution infrastructure and clear policy signals.
[84] LNG, CNG, DME and ED95 represent the main alternatives to diesel engines considered today.
[85] LPG is a by-product of the hydrocarbon fuel chain, currently resulting from oil and natural gas, in future possibly also from biomass

transport. The Fuel Cells and Hydrogen Joint Undertaking[86] is working on projects demonstrating the use of fuel cells for an increasing type of transport vehicles and vessels.

4.1. State of the technology development

Underlying themes of vehicle power cell research are increased efficiency and lowering of noxious emissions. Alternative fuels could help with these aims, but to which extent depends on their characteristics and levels at which alternative fuels are blended with conventional fuels. As a result engine improvement efforts tailored to alternative energies will depend on the levels of gains that could be achieved.

a) Light duty vehicles

Light Duty Vehicle technology and the fuels it uses are driven by tail pipe pollutant emission limits as well as fleet average CO2 tail pipe targets for new vehicles[87]. So far the CO2 targets, and fuel taxation favouring diesel[88], has driven large scale uptake of diesel especially for the larger and heavier vehicles that do significant mileage such as larger passenger vehicles and vans. In the medium term, it is expected that the envisaged new CO2 targets and the implementation of the new test procedure World Harmonised Light Vehicle Test Procedure (WLTP) replacing the New European Driving Cycle (NEDC) in the type approval of the vehicles, will drive a wide-scale uptake of new engine and vehicle technology in the LDV sector, including increased levels of electrification and hydrogen. Concerning pollutants, EU emission standards apply to all motor vehicles and limit the permissible tailpipe emissions of CO, HC, NOx, PM and PN. Very effective after-treatment devices, allowing vehicles to "meet" Euro 6 standards, are available and in operation today although not always to their full effect. These systems, especially the diesel after-treatment systems, can be costly if sufficient manufacturing scale is not reached, which could become another driver to push the development of alternatively fuelled powertrains.

The characteristics of transport fuels are defined by CEN standards[89], which define as well the allowed blending ratio of biofuels, such as ethanol or FAME[90]. Ethanol is the most widely used blend component into petrol and can be blended up to 10% (v/v)[91]; small amounts of methanol and higher alcohols as well as larger amount of ethers are also allowed to be blended into gasoline within current standards. FAME can currently blended into diesel up to 7% (volume)[92].

The introduction of blends going beyond what is specified by the current CEN standards (hence creating the conditions for an even higher uptake of certain biofuels), would require engine modifications except for advanced drop-in biofuels.

One of the expected benefits that could be achieved by a higher blend of alcohols and ethers in petrol derives from their higher octane content which could mean increased thermal efficiency and lower CO2 emissions. Higher FAME blends are possible, but would require

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[86] http://www.fch.europa.eu/

[87] The fleet average CO2 targets for new passenger cars are set at 95g/km for 2021

[88] Diesel / gasoline ratio that is significantly (2.6 in 2015) biased towards diesel "Fuels Europe: Road fuel demand in the EU"; link, DG TAXUD (2015) "Excise duty tables"; link.

[89] Standards exist for Gasoline (EN228), Diesel (EN590) , LPG (EN589), paraffinic fuels (EN15940), B10 (EN14214), and are under development for natural gas and E85.

[90] Alcohol fuel, which can be produced from agricultural, forestry and municipal residues and wastes, can be utilised as a direct replacement for gasoline in internal combustion engine vehicles. Other ethers commonly blended into gasoline are MTBE & ETBE; both are used as octane enhancement as well as to raise the oxygen content in gasoline. FAME: Fatty Acid Methyl Ester Type of ester derived from transesterification of fats with methanol. Is the most common type of biodiesel and can act a direct replacement for diesel in internal combustion engine vehicles

[91] volume

[92] This limit is included in EN 590. The Fuel Quality Directive allows also higher blends.

engine and fuelling system changes and would most likely require higher levels of after treatment.

Another option considered by the automotive industry to reduce CO2 and pollutant emissions from light duty vehicles is natural gas blended with biomethane in a certain percentage. Better performance in terms of air quality and lower fuel price to the users, as a result of lower fuel duty per unit of energy, compared to petrol and diesel are also important drivers.

Natural gas and bio-methane are typically used in light duty vehicles in adapted spark ignition engines. Vehicles with these engines are widely commercially available in Europe directly from the manufacturer. The introduction of a new CEN standard[93] for natural gas and bio-methane use in transport is expected to increase their uptake. Depending on the variation in gas specification allowed in the standard, engine efficiency improvements are to be expected due to the high octane number of methane gas. Significant variation in the make-up of grid natural gas makes engine optimisation a challenge in terms of fuel standardisation[94].

Concerning renewable synthetic paraffinic fuel, there are no real challenges for adoption of these fuels in transport as they are direct replacements of the incumbent fuels. Challenges are mainly around the production process scale and cost effectiveness.

Hydrogen fuel cells are another option for LDV (and also for HDV), but major challenges remain, such as their cost and the availability of a sufficient network of hydrogen refuelling stations.

b) Heavy duty vehicles

Heavy duty road vehicles (trucks and buses) are predominantly powered by diesel engines. This is a consequence of its superior fuel efficiency and low end torque compared to petrol engines. The diesel cycle inherently requires specialist NOx reduction systems. It also has inherently high particulate matter emissions when fuels with carbon to carbon links are used. So far these emissions have been countered by increasingly sophisticated, costly, bulky after-treatment systems. Cost effective alternative fuels and technology that have less after-treatment requirements[95] could therefore play a significant role in powering the HDVs of the future.

Currently the focus seems to be mainly on natural gas blended with bio-methane or pure bio-methane (bioLNG & bioCNG) dependent on duty cycle). This interest is largely driven by the much lower fuel duty per unit of energy compared to diesel. The increase in re-fuelling stations availability has helped the uptake of this technology. Natural gas and bio-methane use in heavy duty vehicles is currently mainly in spark ignition (SI) engines and to a lesser extent in compression ignition (CI) engines. SI engines typically have a lower efficiency than incumbent diesel engines, while compliance with Euro VI standard is simpler as it only needs a three-way catalyst (TWC). The gas is either stored in 200bar on-board pressure

[93] EN 16723-2:2017 is being developed by CEN TC 408 in response to the mandate M475 and has not yet been published. Furthermore relevant are EN 16726 which specifies H-gas composition for distribution in the NG grid (established by CEN TC 234 in response to the mandate M400). A study is currently ongoing to prepare for an update of this standard for it to fully meet the requirements of the mandate; as well as EN 16723-1 containing the specifications for biomethane for injection into the NG grid.

[94] Natural gas is a mixture of methane with lots of other components. This mixture and therefore the properties (incl LHV, RON) of the fuel has very significant temporal and regional variations, that make engine optimisation (and therefore achieving maximum efficiency) more difficult

[95] Due to the elimination for example of cyclic carbon to carbon links

tanks (CNG) or in cryogenic liquid form (LNG). LNG has a higher energy density than CNG and is therefore used for long distance haulage. The technology is commercially available in Europe and it can also be retrospectively added to the vehicle. The CEN standard for natural gas and biomethane[96] for use in transport has been adopted in March 2017 and it is expected to speed up the uptake of gas. Various projects (such as the LNG blue corridors) are currently underway in Europe to increase the infrastructure and technology availability.

Other considered options include a wider uptake of alcohol based fuels either with a premixed ignition improver, as a dual fuel application or in an optimised SI engine. Di-Methyl Ether (DME)[97], and ED95[98] engines have been developed and are commercially available. So far the uptake has been limited largely to buses in Sweden due to infrastructure requirements. Research in methanol with an ignition improver (MD95[99]) is ongoing[100]. While ED95 technology is mature and a reference fuel standard exists, other engine technologies using methanol would need some further development and the fuels standardising as well as overcoming the issues of using hazardous material.

Biodiesel and particularly FAME are already extensively used in HDVs through blending (up to 7% by volume) with diesel. Higher blend levels (up to B100) are used in dedicated fleets, but require engine and fuelling system changes, would most likely require higher levels of after-treatment and entail infrastructure modifications, so might therefore not be optimal from an overall system standpoint. Instead, renewable synthetic paraffinic fuels, produced by advanced biofuel technologies, can be used in high blends or pure in HDVs and can be a direct replacement of diesel.

c) Rail

All Member States rail strategies favour further electrification[101] of the railway network, but there are routes where electrification is not economically viable. On these routes locomotives could be fuelled with alternative energies, including hydrogen, potentially in combination with some form of electrification.

Rail engines are classed and regulated as Non Road Mobile Machinery (NRMM)[102]. This is currently at stage IV with stage V emission regulation under consideration (2004/26/EC directive). The European rail sector set a vision to reduce specific energy consumption by 50% by 2050, and aims to reduce total emissions of NOx and PM10 by 40% and at zero emission by 2050[103]. Developing flexible engine systems able of maximum fuel conversion efficiency, and integrating emissions reduction technologies and hybrid propulsion systems will contribute to achieving these goals. At the same time to meet increasingly ambitious emissions reductions the use of alternative fuels such as LNG, advanced biofuels and hydrogen is considered.

The use of LNG is beginning to gain interest as an alternative fuel. LNG and liquid bio-methane (LBG) offer reductions in polluting PM emissions, and tailpipe GHG emissions in

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[96] EN 16723-2:2017
[97] Di-Methyl Ether Produced by hydration of methanol for use in CI engines. It has similar combustion properties than diesel. It can be derived from a variety of sources, either renewable or fossil (hence it is not by default low carbon).
[98] By Volvo and Scania respectively
[99] Similar to ED95 but with methanol
[100] Developed by the VTT Technical Research Centre of Finland
[101] it is noted that only renewable electricity and renewable hydrogen will have a net positive contribution to transport decarbonisation
[102] Emissions from these engines are regulated by a new Regulation which shall apply as of 1 January 2017 ("NRMM Regulation"); link.
[103] "Rail Sector Strategy 2030 and beyond"

the case of renewable fuels. The well-to–wheels GHG emissions of LNG depend largely on the levels of methane slip and source of the gas. The LNG option is considered for new locomotive development rather than for retrofitting of existing ones, due to the extra-space needed for LNG tanks. LNG use is being demonstrated in Spain, with claims that NOx, CO and PM are reduced by 70%, and tank-to wheels GHG by 20-30%. Trials have also taken place in other countries e.g. Canada and Russia, and small scale liquefaction technology could allow liquefying natural gas at any point along a gas distribution network. Lower running costs associated with LNG are appealing.

Biodiesel (FAME) produced from sustainable feedstocks provides another alternative; however existing diesel traction engines running with blends in excess of B30 can lead to increased fuel consumption and decreased power, and higher maintenance costs. To date the use of biofuels in Europe is limited to a number of trials on rail vehicle and engines carried by rail operators.

Hybrid diesel-electric locomotives can offer significantly reduced energy consumption and lower emissions. If the technology develops sufficiently to be cost-effective, larger scale energy storage on electric trains could provide them the ability to run on non-electrified routes. Another technology considered by the rail industry in the drive towards zero emissions is fuel cells and first trains are becoming available.

d) Waterborne

Approximately 77% of waterborne fuel consumption is low-quality, low-price residual fuel referred to as heavy fuel oil (HFO), which tends to be high in sulphur.

The Waterborne transport sector has internationally recognised standards that define the characteristics of fuel oils and what they can contain, so that they will be suitable for use on-board ships, ISO 8217:2012 being the most widely used standard.

Current research activities in waterborne propulsion are concentrated on combustion systems to reduce emissions and fuel consumption. This includes research on exhaust treatment systems, dual-fuel engines and advanced fuel injection systems to reduce emissions while maintaining or improving energy efficiency. Partially pre-mixed (and other forms of low temperature) combustion systems combined with exhaust gas re-circulation and waste heat recovery are also topics of research. Methane leakage throughout the fuel supply and storage chain could offset the GHG reduction emissions gains by the use of liquified methane and requires further research and innovation.

Currently, the main alternative to HFO is LNG as it is considered a proven and available solution, with gas engines covering a broad range of power outputs. LNG is burned either in stoichiometric or lean burn SI engines, or in dual fuel direct injection (diesel cycle) engines. In the future, LNG and ultimately hydrogen may be used in high temperature fuel cells to achieve greater engine efficiencies.

Depending on the combustion and after treatment technology used, LNG can lead to significant emissions reductions. Reductions of 85–90% for NOx, near 100% for SOx and PM and 15-20% for GHG emissions have been reported[104]. Even though technologies preventing methane slip (the release of unburnt methane) already exist, their effectiveness

[104] Clean North Sea Shipping Project: "Cleanship – final report"; link.

needs to be further improved. In the EU 50 LNG-fuelled ships (excluding LNG carriers) are in operation and additional 45 LNG-fuelled ships are on order.

Methanol is another option attracting significant interest[105] response to the need to reduce SOx emissions. Methanol is used in diesel engines, using a small amount of pilot fuel for ignition[106]. It is considered suitable for inland as well as for short-sea shipping, where it is currently being tested. The conversion of an existing engine to burn methanol would bear less costs than an LNG retrofit, and methanol has a heating value close to LNG[107], which entails a similar performance. On the other side methanol poses a number of new challenges to operators in terms of handling and safety due to its relatively low flashpoint, toxicity (skin contact, inhaled or ingested) and denser than air vapour.

Furthermore, low grade bio-oils produced by advanced biofuel technologies, namely from biomass wastes and residues, could present a sulphur-free, low particulate and NOx emissions solution.

e) Aviation

Technological progress and operational improvements have increased significantly the energy efficiency of air transportation. However, even with the most radical technological and operational progresses, the efficiency gains will not offset the expected traffic growth. Thus under ICAO the international community agreed on the Carbon Offsetting and Reduction Scheme for International Aviation imposing to airlines to offset the growth of their CO2 emissions after 2020[108].To contribute to the fulfilment of this latter goal increasing attention is being paid to the development of drop in fuels produced from renewable sources.[109]. The composition of these new fuels is currently mostly paraffinic. There are 5 major fuel routes approved for use in civil aviation[110]. These alternative fuels are used blended with conventional Jet-A1 according to the limits established by the standard ASTM 7566. Blends up to 50% (FT-SPK and HEFA-SPK fuels), 30% (ATJ-SPK fuels) or 10% (SIP-SPK fuels) are accepted for commercial operation .Once blended, the fuel is considered as Jet-A1 and can be used in all civil infrastructures and aircrafts that use jet fuel without any segregation[111].

To date SPK has not been used in Europe on a large scale (with local exceptions e.g. in Oslo[112]); most of the production and use so far had been for demonstration and/or research and innovation purposes. Recent interest in developing these fuels has been encouraged by developments in technology leading to increased availability and affordability. Due to the investment and time needed for the approval of new technologies for use in aviation, however, time to market of these new technologies could be significant without support[113]. Currently there is no production of drop-in fuels for aviation in Europe, as the only incentive for airlines using bio-jet fuel is provided by the EU ETS for intra-European flights which is

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[105] For example Stena Line decided to retrofit one of its vessels to use methanol
[106] MGO: (Marine Gas Oil), Oil made from distillate only or HFO (Heavy Fuel Oil) Pure or nearly pure residual oil
[107] LNG with 20.3 MJ/litre and methanol has 19.8
[108] ICAO agreement (link)
[109] ICAO agreement (link)
[110] Approved pathways: FT-SPK, HEFA-SPK, HFS-SIP, FT-SPKA/A and ATJ-SPK . There are other seven routes currently under approval process, plus other 15 waiting to enter the process. Steve Csonka (2016) "CAAFI – CORE-JetFuel Cooperation Workshop"; (link).
[111] ASTM (2016) "ASTM D7566-16, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons"; (link).
[112] Since the end of 2015, all flights departing from Oslo airport (Gardermoen) have used a biojet fuel blend (below 3%), which corresponds to about 60,000 flights and about 6 million of passengers. Today Oslo airport continues the use of biojet in its commercial flights with supply from Altair in USA.
[113] For example, the approval of the latest technology from alcohols (Alcohol-to-Jet - ATJ) has taken more than 5 years to be approved with costs in the range of several million euros. EPA (2014) "Reducing Emissions from Non-road Diesel Engines"; (link).

negligible compared to the price gap. However, the recognition of the importance of advanced biofuels for aviation at a global level and the ICAO agreements for a Global Market Based Measure for reducing CO2 emissions from international aviation are expected to accelerate the global biojet deployment[114] and facilitate establishing the necessary regulatory framework that will support its up-take.

f) Initial analysis of options available and level of maturity of low emission alternative energy for transport

Fuel Type	Power train	LDV	HDV	Waterborne	Rail	Aviation
Methane based liquid & gas	**SI**	Commercial	Commercial			
	CI		Current dual fuel technology unable to meet Euro VI. New compliant technology under development & potentially available in 2017	Commercial as dual fuel and dedicated gas engine applications.	Under development	
	Turbine			Research stage Deployed for military vessels and some passenger ships. Near deployment for LNG carrier		
Hydrogen	**Fuel Cell (FC)**	Commercial (first cars available for purchase at premium cost)	Commercial for buses ((still at premium cost), at development stage for trucks)	Research stage; exploiting availability of LNG in harbour and on ships	First deployment of hydrogen fuel cell regional train	
LPG	**SI**	Commercial	Under development		Research stage	
Alcohols, ethers, esters	**SI**	Commercial - Ethanol and M&ETBE are widely blended into gasoline. Use of bio-ethanol in particular 2nd generation.	Under development	Under development		
	CI	Commercial - FAME widely adopted as blend with diesel. Use of advanced biofuels.	Commercial - DME & ED95 in dedicated fleets. FAME widely adopted as blend with diesel	Commercial as dual fuel application with methanol.	FAME use under development. Other fuels at research stage	
	FC	Research stage	Research stage	Research stage	Research stage	
SPF	**SI**					
	CI	Commercial – HVO used in vehicles. Under development – FT-diesel properties being investigated	Commercial – HVO used in vehicles. Under development – FT-diesel properties being investigated			
	Turbine/ Turbofan		**Research stage**			**Commercial – HEFA in use. Under development - various SPK fuels**

[114] Already, TOTAL is converting the oil-refinery in La Mede, France to a bio-refinery with 500,000 t/y HVO biodiesel and HEFA biojet capacity with planned inauguration of operations in 2018.

4.2. Focus areas for action

Decarbonisation will depend on the well-to-wheel implications of alternative energies production and use, and will need to rely on low carbon and renewable fuels. Research and innovation options should include more efficient use of advanced biofuels, fossil fuels blended with renewable fuels or pure renewable fuels in transport and in particular for heavy duty vehicles, aviation and shipping with a focus on matching fuel and engine characteristics. Furthermore research and innovation should look into applications combining electric, fuel cell and renewable fuels, e.g. vehicle fuel cell concepts for on-board generation of power from renewables.

A number of alternative fuel options could be deployed in each mode with benefits in terms of optionality and energy diversification. Some transport modes (LDV and some HDVs) however have the option of substantial electrification, as outlined in the Electrification chapter or of the use of fuel cells. The maturity level of these options is defined in the table above. Therefore, the development of LDV technology has a lower priority than in transport sectors where there is no alternative.

It has to be noted that the use of alternative energies for combustion may help decarbonisation but should also at least comply with current emission requirements for air pollutants such as PM and NO2.

4.3. Outlook for research and innovation actions until 2050

Due to the intrinsic link between the production and the use of alternative fuels, research and innovation actions in the transport sector have to be closely analysed and developed together with the respective options for energy research and innovation. At this initial stage, the focus was on taking stock of the technological development and outlining possible options for future analysis. Under the future governance arrangements for the strategic transport research and innovation agenda and in close cooperation with the Energy sector's Strategic Energy Technology Plan (SET-Plan and its governance), concrete research and innovation focus actions and timelines will be developed and implemented.

5. Network and traffic management systems

At present, there are numerous bottlenecks within and across transport modes resulting in system-wide capacity constraints, traffic jams and increased levels of environmental impact. Lack of timely information, reliability, coordination, passenger comfort, safety/security and accessibility of collective passenger transport, railways and inland waterways for freight transport all lead to an increased use of individual transport by road.

With the proliferation of digital technologies and the emergence of the connected traveller it will be easier to influence real-time demand by shifting demand in time (out of peak hours) and space (to alternative locations or routes through intelligent applications and user information services. Integrated urban traffic management and mobility information systems can contribute significantly to optimising transport flows through cities and in rural regions.
Cities and rural areas can enable greater public transport capacity and efficiency by providing door-to-door mobility information and guidance systems and by facilitating intermodal travel chains. In conjunction with active traffic management strategies for prioritising sustainable modes of transport, digital mobility innovation offers a significant opportunity for cities to optimise, transform and sustain integrated public transport systems.

The transition towards an advanced multi-modal transport system requires the effective optimisation of the entire transport network, across a number of performance areas. Active network management and a better orchestration, organisation and optimisation of traffic flows in the system play a key role in this process.

The shared use of physical infrastructure (e.g. off-peak use of underground or light-rail passenger networks for goods distribution) could provide for significant modal shift potential by moving goods delivery from road to (electric) rail systems. Where available, better integration of water-borne urban passenger and goods mobility could also provide for more efficient and sustainable use of existing urban transport infrastructure.

The enhancement and standardisation of performance objectives and requirements should be considered for effective optimisation of network and traffic management systems (NTM). This would include performance enhancements in a number of Key Performance Areas (KPAs), such as environmental sustainability, capacity, safety, (cyber-) security, cost effectiveness, predictability, efficiency, flexibility, customer mobility performance and satisfaction levels, as well as other/qualitative objectives (e.g. increasing automation levels, cross-modal integration, evolving human factors).

This is particularly important, given that the development of advanced NTM systems requires several performance trade-offs to be considered. For instance, regulating traffic vs. longer journey times; providing extra capacity vs. additional cost; prioritising low-emission vehicles vs. cost of retrofit/forward fit.

The uptake of efficient technologies can also significantly reduce the investment costs of new vehicles, infrastructure and (non-) technical solutions. The development and production costs of innovative technologies could be reduced by the introduction of business and standardisation processes, in terms of simplification and harmonisation of technical specifications and administrative, organisational and operative procedures. In general, a common agreement framework must be established between the various stakeholders and actors.

5.1. State of the technology development

At present, there are numerous bottlenecks within the four modes of transport (air, rail, water, road) and across multiple operating environments: producing sub-optimal levels of transport performance, severe capacity constraints, unmanageable traffic jams and undesirable environmental/emissions outcomes. The lack of efficiency in the management of traffic flows can be a major cause in the decrease of attractiveness of collective transportation for passengers and the share of railways and inland waterways for freight transport. Other major causes are the lack of timely information, reliability, coordination, passenger comfort and accessibility. The consultation process on NTM systems gathered the views of a wide range of transport experts and stakeholders which concluded on the following:

a) Road

On urban roads, a significant improvement of mobility of people and transport of goods requires a better management of all kinds of vehicles (from conventional to autonomous vehicles), vehicle fuel technologies (from fossil to alternative fuels), bicycle and vehicle sharing, dial-a-ride, road public transport and paratransit, walking and cycling. This problem is particularly evident in highly dense urban and metropolitan environments. For modal shift and effects on GHG, short trips play an important role. Also due to growing urbanisation, shorter trips will increase and these short trips will need to shift to soft modes of transport (e.g. bicycles).

On extra-urban roads, the requirements are to achieve a safe, efficient and sustainable road transport in order to offer connected mobility, less congestion, fewer accidents, less pollution, improved levels of EU-wide multimodal travel information services. These objectives require investments on (C-) ITS[85] and connected driving technologies.

b) Rail

In railway traffic management, the increase of heterogeneous (local, international and freight) traffic flows requires an improvement in planning and management of traffic flows (including better train timing, ordering and routing decisions). The key elements to improve are the management of traffic flows at cross-border sections (especially when using different signalling and train operating systems), rail terminals connecting rail with other transport modes (including rail-road terminals, advanced rail-rail trans-shipment yards, shunting yards, terminals in inter-modal logistic areas, depots for rolling stock), complex and densely used conventional railway stations for passenger trains in urban areas (hosting local/high-speed/international/freight traffic).

c) Waterborne

European ports, rivers and canals play an important role in global supply chains, since a very large percentage of global merchandise trade is carried by sea and handled by ports worldwide. The current challenge faced by carriers, port operators, freight forwarders and shippers includes the following issues: improving the traffic flows between ports, better handling of loading and unloading requirements in each port, better synchronising of management of resources and vehicles inside/outside the port areas, effectively managing inter-modal connections with expanding port hinterlands, providing seamless door-to-door inter-modal transport services for customers, increasing maritime connectivity via trade liberalisation strategies.

d) Aviation

In the aviation sector, the objective is to achieve a Single European Sky, in order to improve Air Traffic Management in Europe. The current bottlenecks are hub capacity, management operations (improving the movement of aircraft, cargo, passengers, baggage at gateways, taxiways, runways and during landing/take-off procedures) and en-route coordination of traffic flows between/outside European hubs. The key elements to improve are modernisation, harmonisation and synchronisation of Air Traffic Management systems (including wider use of Global Navigation Satellite Systems, better aircraft trajectory & route planning, collaborative network management, flexible airspace management, integrated management of en-route and terminal control areas, inter-modal air transport connections and drone air traffic insertion / U-Space).

Large-scale intelligent and interoperable traffic management and information systems are key to the better use of the capacity of the existing and future infrastructure and to optimise traffic flows with heterogeneous vehicles. The collaborative decision making and system-wide information management proposed for air traffic management (SESAR), the advanced signalling and railway traffic management system (ERTMS), the maritime transport and maritime traffic monitoring and information system (The Union Maritime Information and Exchange System SafeSeaNet), the real-time river traffic information system (RIS) and cooperative intelligent transport systems (C-ITS), as well as initiatives on multimodal transport management and information systems play a key role in speeding up the deployment of smart and intelligent mobility systems for improved traffic monitoring, control and communication to the traffic controllers and vehicle operators.

The European global navigation satellite system (Galileo) has the potential to allow new opportunities for efficient tracing and tracking of vehicles, e.g. pilots are currently being under investigation for train control, delivering to traffic management reliable real-time information.

Important enabling developments relate to:

- **Data availability and processing**: transport systems need – and are increasingly able – to aggregate and analyse data from multiple sources and networks to dynamically respond to demands and operate more efficiently. Overall benefits relate to:
  - Data provision from sensors that are smaller, less expensive and more reliable;
  - Artificial intelligence systems, machine learning and data processing capabilities that are improving, and transport networks that are becoming increasingly 'connected' (via more reliable wireless internet connectivity, increasingly accurate GPS, etc.);
  - Sensors and data processing capabilities that are increasingly interconnected via the 'Internet of Things' (IoT); traffic networks and infrastructure are "learning" from the data collected and adapting toward greater efficiency;
  - Growing data storage capacity that allows for larger amounts of data to be stored relatively easily and at little cost.

- **Mobility optimisation**: 'Big Data' collection and analysis (from multiple transport networks, public and private) and path optimisation algorithms can intelligently schedule and reschedule journeys to avoid bottlenecks, sensibly distributing commuters during busy periods (such as rush-hours) to smooth traffic flow and increase the efficiency of the entire transport network. Vehicle-to-vehicle (v2v) and vehicle-to-infrastructure (v2i) communications will allow for increased safety and greater (energy) efficiency on the roads. However, smart traffic management systems must ensure international interoperability to allow for an environment of competitive solutions to evolve across the EU. Traffic optimisation strategies will need to be a component of overall transport and mobility system governance and management, rather than focus on optimising conventional vehicle flows which can create further unsustainable demand.

These enablers are driving innovation and development towards connected mobility and integrated transport information management systems, however existing governance and management systems are often constrained by sectoral regulation and management focus. Current infrastructure governance often does not yet allow for seamless data connectivity across separate infrastructure systems such as mobility, energy, and built environment and across both private and public service users and providers.

5.2. Focus areas for action

The following table summarises key milestones for the different transport modes, showing interdependencies and the need for coordinated actions.

	2020	***2030***	***2050***
Air	*High Performing Airport Operations; Optimised ATM Network Services; Advanced Air Traffic Services; Collaborative Decision Making; U-space and other SESAR initiatives*	*Advanced Support for Conflict Detection and Resolution with Application to En-Route and/or Terminal Manoeuvring Area Control*	*(Semi) Automated Control of Multi-Area Traffic Management System on Single European Sky*
Rail	*ATP, ERTMS Level 1 / 2; Driver Advisor Systems; "Shift2Rail" Initiatives*	*ERTMS Level 2 / 3; Driver Advisor Systems; Advanced Decision Support Systems for Multi-Area Traffic Management System on the Core Network*	*ERTMS Level > 3; (Semi) Automated Control of Multi-Area Traffic Management System on the Core + Comprehensive Network*
Road[115]	*Piloted parking* *Truck platooning*	*Highly automated vehicles* *• Cooperative Merging* *• Overtaking Assistance* *• Intersection Assistance* *• Dynamic Platooning* *• VRU Assistance*	*…*
Water	*Vessel Traffic Management Information System (VTMIS); Integrated Maritime Services; Safe and (cyber-) secure maritime transport and traffic reporting, monitoring and information system; Real-time River Information System (RIS)*	*Advanced Decision Support Systems for effectively managing and synchronising inter-modal connections of the waterborne transport to the Core Network*	*(Semi)Automated Global Control of Shipping, Ports and Maritime Logistics*
NTM	***Indicators and reference assessment***	***TEN-T core network***	***Fully multimodal and interconnected EU transport***

[115] Sources: http://www.ertrac.org/ ;

5.3. Short term research and innovation actions and outlook for research and innovation actions until 2050

The following table provides suggestions for key actions and timing as well as first estimates of total efforts needed for research and innovation actions until 2050 (short term until 2020; medium term until 2030; long-term beyond 2030):

STRIA NTM – Top 10 Priorities / Building Blocks for Research and Innovation

Building block	Phase	Key R&I themes *("What")*	Timeframe *("When")*	Instrument *("How")*	Lead actor *("Who")*	Cost[1] *("How much")*	Impact on Energy Union[2] *("Benefit")*
1	DESIGN	Architecture and Concept of Operations for an efficient, resilient and adaptable multi-modal NTM system	Short term	Research	EU	Low	Low
2	DESIGN	Development of multi-actor Organisational and Business Models with shared responsibilities	Short term	Policy Support	EU	Low	Medium
3	DESIGN	Research and validation of next-generation multi-modal NTM systems (including intra-modal optimisation and development of interfaces)	Short term	Research / Innovation	EU / Industry	High	Medium
4	DESIGN	Integration of infrastructures, vehicles, systems and services into a truly multi-modal network	Short term	Research / Innovation	EU / Industry	Medium	Medium
5	OPTIMISATION	Demand-Capacity Balancing for efficient journey management (passenger & freight)	Medium term	Research / Innovation	EU / Member States	Medium	Medium
6	OPTIMISATION	Calibration of arbitration models for complex NTM scenarios and multi-actor settings (optimising multiple performance targets and user vs. network needs)	Medium term	Research	EU	Low	Medium
7	OPTIMISATION	Traffic optimisation of conventional, (semi-) automated and unmaned vehicles within a multi-modal NTM system	Medium term	Research	EU / Industry	Low	Medium
8	EXECUTION	Large-Scale Demonstration of fully multi-modal NTM capability in any operating environment (Urban, non-Urban)	Long term	Innovation	EU	High	High
9	EXECUTION	Resource and asset management optimisation for advanced NTM systems	Long term	Innovation	Cities / Regions	Medium	High
10	EXECUTION	Piloting an efficient multi-modal NTM system across European hubs / nodes (incl. integration of non-EU traffic)	Long term	Innovation	Member States	Medium	High

1. Cost of NTM Roadmap:

Preliminary estimate in the range of c. EUR 7-10 billion for R&I by 2050.

NB: This includes EU, National and Industry R&I resources, on top of existing budgets. As a reference, only SESAR (traffic management for one of the four transport modes) has received R&I funding over two 7-year periods until 2020 of c. EUR 3.7 bn (1/3 from the EU). Furthermore, EU Transport R&I budget for 2018-2050 could amount to c. EUR 30 bn (i.e. five 7-year periods, c. EUR 6 bn each as in H2020), to be allocated across all 7 STRIA Roadmaps (e.g. EUR 4 bn each) and attract further public/private leverage (at least 1:1). Finally, deployment / investment costs are not included, hence only referring to R&I cost (NB: SESAR deployment costs are c. x10 the costs of R&I).

2. Contribution of NTM Roadmap towards Energy Union:

Preliminary estimate in the range of c. 7%-10% of the overall 60% transport decarbonisation (GHG) target by 2050.

NB: This estimate refers to the benefit realisation from the actual deployment and operation of next-generation / multi-modal NTM systems up until 2050. As a point of reference, SESAR estimates a reduction of up to 10% in Aviation CO2 emissions. Furthermore, all 7 STRIA Roadmaps are estimated to contribute on average 8.5% towards the 60% GHG target. Applying a sensitivity of +/- 20% (i.e. 1.5 percentage points on each side), this implies an estimated range of 7-10%. Finally, any contribution from NTM is also dependent on the delivery of the other STRIA Roadmaps, all together being required to make a collective contribution towards EU / Energy Union goals.

6. Smart mobility and services

Significant changes can be observed in user behaviour and lifestyle in relation to transport that will affect the decarbonisation impacts of new service models in the transport sector. Younger generations are currently opting for reduced motorisation rates and modal shift away from daily use of the automobile and towards multi-modal shared, public and active travel modes. Overall, transport users are embracing digitalisation and the use of smart phones, mobile web applications and social media. These behavioural shifts are supporting new shared mobility and transport business models, services and markets, which collectively open new pathways to sustainable mobility. If such behavioural trends persist, they can provide a principal support factor for decarbonisation, provided that use innovations are building on decarbonised mobility systems, potential rebound effects are mitigated and expected higher mileage and faster turnover (shorter lifetime) of shared vehicles are addressed.

6.1. State of the technology development

Digitalisation is currently reshaping the sector. ICT-enabled web, mobile and big data applications are spawning new mobility and transport services and systems. Traditional automotive, public and private transport models are being challenged as new players are emerging with disruptive service offerings; many of the new models are blurring traditional demarcations between public transport and private mobility, including in the area of urban logistics. Mobility-as-a-Service (MaaS) will increasingly catalyse the public-private co-development and co-delivery of mobility and transport systems and services, as well as shared and open use of public space, data and infrastructure.

The potential for decarbonisation depends on a better utilisation of underused assets in transport fleets and infrastructures to accommodate passengers demand and reduce the share of unsustainable travel modes. Smart mobility systems can help to accommodate this potential and also address persistent problems of congestion and accessibility.

There is a critical link between new technologies and services and transport decarbonisation. The potential carbon mitigation performance of emerging new technologies and services such as multi-modal, electric, autonomous, low-altitude aerial, vertical and on-demand mobility has not yet been extensively evaluated, in particular in their integrated application. They can strongly support a shift to transport decarbonisation, or further lock in unsustainable travel behaviour. A key task will be to establish empirical validation of the sectoral and systemic decarbonisation impacts of such technology, systems and services innovation, and ensure that technologies and service innovations are not taken forward for their own sake, but in view of achieving a transition to a low-carbon, efficient and accessible transport system.

6.2. Focus areas for action

Smart and sustainable cities

Future transport and mobility services cannot be envisaged as stand-alone sectoral solutions. Given the significant urbanisation in Europe, these will need to be embedded in wider smart and sustainable city strategies aimed at increasing urban resource efficiency and decarbonisation incl. developing and implementing new and clean technologies as well as a geometry of green zones and transport access zones. Smart mobility services will need to interface with multi-sectoral and city-wide strategies for optimising the use of energy, spatial, economic and material resources. Cities should not been seen as stand-alone systems but as embedded in larger regional and European and global mobility systems. Sustainable and efficient linkages between future urban and extra-urban transport networks, including rail and air travel systems, will need to be developed as well as innovative solutions answering the needs of rural dwellers and contributing to development of Smart villages[116]. Shared electric vehicles within and across corporate and public fleets increase availability and attractiveness to the public.

Demand and land use management

If individual mobility services can be integrated with public transport systems, the overall efficiency of urban and rural mobility systems can be greatly enhanced and thus contribute to avoidance of unsustainable modes and to efficient demand management.

With regard to logistics and delivery services, smart mobility services enable avoidance of unnecessary vehicle movements by making last mile deliveries more efficient by consolidating goods flows and moving towards smaller and lighter freight vehicles (such as electric cargo bikes). A key challenge will be to develop more viable shared data, infrastructure and logistics business models for urban goods distribution that deliver a more efficient utilisation of public transport infrastructure across both passenger and goods transport modes.

The contribution of mobility service innovations to sustainable demand and land use management is thus dependent on their embedding in an overall mobility and transport strategy for the whole city. New economic and technological trends influence land use patterns and people's lifestyles. Digitalisation, on-demand mobility, flexible and cleaner production can increase the chances of higher density development and a more balanced mix of land uses (residential, commercial, production, schools, parks), potentially reducing demand for unsustainable travel modes. Identifying and validating the positive contribution that new mobility services and systems can make to sustainable, transit-oriented development should be of central concern to European innovation efforts.

Modal shift

A reduction of personal-use and single-occupancy vehicles requires adequate options for public transport, other shared transport, as well as cycling and walking. Across a number of European cities daily travel modes have shifted away from the automobile towards public transport or active travel (London, -12%, Berlin -8% from 1998-2013, Brussels -18% from 1999-2010).

New technologies, big data and real-time information on demand and supply will make these tools more efficient in promoting modal shift. The measures include financial measures (dynamic pricing of road-use and parking), mobility budgets, business models for mobility-as-a-service, incentivizing sustainable modes over individual car use, regulatory interventions to restrict access to sensitive areas and parking, integrated intermodal terminals and park and ride services, integrated ticketing and real-time information covering all modes.

[116] https://ec.europa.eu/agriculture/sites/agriculture/files/rural-development-2014-2020/looking-ahead/rur-dev-small-villages_en.pdf

While it is currently not realistic to expect that all car travel can be shifted to other modes, it is desirable that car travel shifts to more sustainable practices by promoting carpooling and ridesharing services together with the transition towards electric mobility and modal shift towards public transport and active modes (cycling, walking). Car-sharing and short term rental in principle do not reduce passenger/vehicle kilometre ratios and as such do not constitute modal shift, but they have the potential to decrease the overall amount of vehicles simultaneously using roads.

Smart mobility services in public and private passenger transport

Smart public transport services and systems can provide the backbone for future integrated smart mobility. Allowing multiple infrastructures to integrate and communicate with one-another, can pave the way for 'one stop shop' platforms that consolidate multiple forms of transport and provide 'mobility as a service'. Car-sharing schemes (both point-to-point and station-based networks) continue to grow in number throughout Europe, with automotive manufacturers and traditional rental-car companies currently dominating the market. A convergence of sharing providers and mobility services models is to be expected. Technological, socio-demographic and behavioural change are facilitating a move towards multimodal transport – combining walking, cars, buses, bikes, trains and other forms of shared transportation. Driven by the transition from "owning" to "using", Mobility as a service (MaaS) enables multimodal mobility by providing user-centric information and travel services such as navigation, location, booking, payment and access that allow the use to consume mobility as a seamless service across all existing modes of transport.

Primarily software-driven, MaaS is the precursor of specifically-designed 'Mobility on-demand' transportation hardware and services. The transformation of transport and mobility services presents a unique opportunity to develop post-fossil, user-centric, smart systems based on access to individual, public, shared and active mobility, rather than ownership of private automobiles. This in turn requires the integration of personal electric vehicles into multi-modal public transport and mobility-on-demand systems to provide users with a flexible and convenient access to a range of travel modes while socialising the high initial costs of switching to electric vehicle-based mobility.

Integrated Mobility-on-Demand services can contribute to modal shift to public transport and also address the inefficient use of infrastructure by private individual motorised transport. User-centric urban mobility systems will provide ubiquitous check-in/check-out user access to enable both inter- and multimodal mobility on demand and enhance overall transport efficiency. In future integrated and sustainable mobility-on-demand systems, electric mobility will become a component of both private and public transport infrastructure and systems. Developing and testing smart integration of tariff structures, data and user interfaces as well as the disposition of rolling stock across these sectors is a central challenge, including new business models and scheduling, booking, navigating, ticketing and charging solutions. Autonomous electric vehicles are expected to form a significant component of 'mobility as a service'.

Smart mobility services in freight and logistics

Significant growth in small-goods and large-goods logistics activity is to be expected; by 2050, freight activity is expected to increase by as much as 250%. Strong growth in online retailing and attendant increases in freight volumes and last mile goods delivery are leading to rising carbon emissions from road-based freight distribution. Future mobility and transport services cannot be viewed in isolation from future urban logistics. The rise in urban goods traffic will lead to further conflicts and capacity constraints on the use of urban space and thus is inextricably linked with overall transport transformation.

Systems, freight and logistics

The evolution of smart systems for cooperation between infrastructures (road, rail, air, shipping) aiming at seamless freight transport will be crucial in facilitating increased capacity – from the port to the last-mile. Loading and unloading cargo that is electronically tagged (thereby carrying all required information to allow for reliable international tracking and reduced border delays) onto autonomous convoys of self-driving trucks will be aided by automated robotics systems.

Wide-scale deployment of autonomous freight shipping is imminent; increased mobile internet availability, adoption of (and developments in) Differential GPS and Automatic Identification Systems and advancements in computer vision will accelerate a transition towards crewless cargo ships and fully autonomous docks. Logistics will also become increasingly smart, as artificial intelligence advancements (such as machine learning) allow for the leveraging of data collected throughout the transport chain, rapidly identifying bottlenecks, solving path optimisation problems, and coordinating efficient flows through and across infrastructures.

It is becoming increasingly likely that many of the future smart mobility services envisaged for personal transportation - electric, autonomous, shared, and connected - will initially be developed and implemented in the goods delivery sector (i.e. logistics) which is already leading innovation in many of these areas. Given health and safety, regulatory and political concerns regarding autonomous vehicles and the application of total data and user transparency, steady-state integrated and electrified mobility-on-demand systems are likely to be deployed in freight distribution first. In this section, new freight and logistics services and systems are reviewed against the same evaluative framework as personal transport systems regarding the potential for decarbonisation.

6.3. Short term research and innovation actions and outlook for research and innovation actions until 2050

Drones and low-altitude aerial mobility

A rapid proliferation of drone technology is taking place due a combination of forces, such as technological transfer from other industries, ‘bottom-up’ open innovation practices such as accessible platforms and collaborative research and significant R&D drives from large companies looking to operate commercial drones in the retail sector.

The integration of vertical urban mobility into existing horizontal transport systems will add further complexity to the organisation of the urban transport and mobility services. Early evidence indicates that light-weight drone platforms can deliver both economic and energetic efficiencies in the short-range distribution of small good. Effective integration of drone-based delivery systems with other urban logistics, public transport and building services infrastructure is a promising innovation vector. Drone and low-altitude aerial mobility is now technically possible for passenger transport also and the combined demand for such on-demand vertical urban mobility solutions will require significant governance, regulation (esp. for the "U-Space") and infrastructure innovation.

Establish better operating models

Effective collaboration of cities, users, researchers and industry should be a central theme in the development of smart mobility technologies, solutions and systems. To meet the challenge of decarbonisation publicly owned and operated systems (such as backbone public rail and bus networks) must work in tandem with private services (such as shared electric and autonomous vehicles), all of which will utilize new technologies that will need to be developed with both public and private investment. New operating models are required to allow public transport and mobility services to collaborate effectively with private individual mobility providers in co-delivering sustainable mobility and transport systems. From a municipal and regional institutions perspective, this will require innovative approaches to cross-sectoral planning, public participation and procurement and the shared use of embedded physical and technical infrastructure.

Development of integrated mobility systems

A core focus should be to enable cities, users, researchers and industry to collaboratively devise multi-stakeholder solutions to the complex problem of mobility and to test and develop them at sufficient scale. It is in the interest of all stakeholders that the private and public sector collaborate not just on research, but on on-the-ground operations such as data sharing, network and infrastructure access, and the development of inclusive user interfaces. The burden of research and analysis should be shared by the private and public sectors, as each will rely on the other for effective technological advancement and sustainable use innovation.

Sharing Data and Infrastructure

Companies, governments and public entities should be equally encouraged to provide collected user and urban data on the use of public space and infrastructures wherever it is available (in such a way that protects the privacy of its citizens) so that users, cities, third party apps, operators, developers and innovators can access it to inform their decisions and innovate their applications. Smart mobility and cities will combine publically and privately developed infrastructures; only by making data (such as aggregate dynamic mobile phone and traffic data, the real-time location of buses or the accurate arrival time of trains) ‘open’ will third parties be able to integrate it into their systems and establish truly ‘cross-infrastructure’ integrated mobility systems.

Future interoperability

Support in the development of EU Technical Standards for communication and interoperability of user devices, critical infrastructures, v2v and v2i will be vital. It is important that such standards can evolve and adapt with technologies to prevent innovation stagnation. This should encompass a dialogue between users, governments, science and industry (including both incumbents/long-term players in the mobility sector and startups). Multi-stakeholder standard setting will allow for the most intelligent standards to be adopted; such standards should not be too prescriptive (thus hindering innovation and technological developments), but should also facilitate robust privacy frameworks and international interoperability to as great an extent as possible.

Carry out large-scale and city-led lighthouse demonstrations which:

- lead to sustained integration of solutions into city operations at real scale (beyond small scale pilots) and at the spatial level of the daily urban system (DUS) to pursue long-term decarbonisation impacts;
- develop the strategic capacity of municipalities and regions to manage integrated transport systems and infrastructure;
- effectively integrate partners from government, research, industry and users in the shared development of future mobility and transport services and systems in real-world settings;
- contribute to the integration of new mobility service innovations with existing (public) transport infrastructure into an overall urban mobility system, allowing for optimal use of infrastructure for passenger and freight transport;

Develop and test innovative and robust arrangements for public-private co-design of transport and mobility services, addressing in particular:

- the shared and efficient use of existing physical transport infrastructures, (in particular backbone transport infrastructures, parking structures, delivery nodes and intermodal hubs), across public, private, passenger and freight sectors and modes;
- the secure collection, management and protection of user and city data in public and commercial open data platforms and public digital infrastructures;
- the enabling of real-time, informational, transactional and operational interoperability across public and private service providers, municipal operators and individual users;
- the innovative integration of access, tariff and user interface systems for public and private transport and mobility services.

Develop and test implementation of governance, regulatory, and public procurement strategies that:

- integrate indicators and urban plans to measure impact on transport decarbonisation and sustainable land use;
- strengthen the development of integrated planning tools and open, real-time data systems to allow for the validation and optimisation of integrated mobility eco-systems against overall sustainability targets (e.g. SUMPS);
- Enable integrated and strategic public procurement of open, interoperable and cross-sectoral solutions.

7. Infrastructure

Infrastructure comprises the basic physical facilities and installations necessary for the operation of road, rail, civil aviation, inland waterways and shipping, plus the additional infrastructure necessary for the propulsion and refuelling of transport vehicles, the coordination, monitoring and management of transport, ensuring secure and safe operation, and allowing for the transfer of passengers and freight. Infrastructure includes physical networks, terminals and intermodal nodes, information systems and refuelling and electrical supply networks. Infrastructure innovation will be vital for implementing the TEN-T network.

Transport infrastructure in the EU faces some key challenges, especially in the areas of governance; pricing, taxation and finance; syncromodality, intermodality, interoperability and integration of transport systems; life cycle optimisation; and infrastructure operation.

7.1. State of the technology development

Transport infrastructure includes the fundamental facilities and systems serving operators and users in the following perspectives:

- urban public transport networks—including light rail (metro and tram), rail, bus, urban motorways and bus lanes;
- inter-urban or inter-regional —including motorways, main line inter-city and high speed rail, inland shipping, domestic aviation;
- international gateways – airport hubs and major sea ports— along with other regional ports and airports.

In addition, there is extensive supporting infrastructure

- traffic and transport control systems, aimed at ensuring safe, secure, efficient, reliable and resilient transport for all modes of transport;
- fuel distribution infrastructure
- information and communication technologies used for customer information, and for tracking, charging, ticketing and billing;
- areas for logistics activities including logistics hubs, dry-ports and distriparks;
- energy facilities including electrical traction power networks necessary for infrastructure and transport operation.

The existing infrastructure continues to evolve with investment by infrastructure owners to accommodate changing demand, changing vehicle types, and to improve network performance. Examples are the construction of new container terminals to accommodate the latest generation of post-panamax large container ships, or the installation of electric vehicles charging points. The latter are predominantly installed in urban areas by public authorities to encourage use of zero emission cars.

7.2. Focus areas for action

Infrastructure Governance

Research should particularly consider new technology-based tools, including social media, to engage the population in local proposals for reducing emissions – either through charging or through other initiatives to change travel patterns.

The development of a common EU tool for the assessment of transport infrastructure vulnerability in natural or man-made disasters would be beneficial in setting best practice across member states, and would be available to transport infrastructure owners such as local governments, who do not have capacity to research and define standards for themselves. Innovation is needed to strengthen transport planning and provision across regional and state boundaries, both for strategic network planning and at an operational level. This includes coordination with Air Quality Plans (under Directive 2008/50/EC) at local and regional level and National Air Pollution Control Programmes (under Directive 2016/2284). Stronger governance is also necessary to encourage research into the medium and long term reduction of emissions via transport infrastructure. That governance should then incentivize the application of research to full effect.

Infrastructure charging

Whole life (building – maintenance – recycling) GHG emissions are not routinely considered at the planning stage for new infrastructure, they are rarely considered for upgrade or operational changes to transport and their costs are not always reflected in infrastructure charges. Better methodologies are needed to make best use of infrastructure charges in order to support relevant policy goals, in particular to promote greener mobility.
Research projects can help to establish new infrastructure charging approaches for all transport modes in Europe. Such approaches could reflect several policy goals for which adequate future models could be developed, tested and analysed with a view to proving validated options for policy and decision makers. The models could in particular support new approaches to increase efficiencies, reduce emissions, increases digitalisation of mobility and transport and foster new business models compatible with fair competition and seamless integration among modes. Research and innovation into both passenger public transport and road vehicle charging systems to allow for interoperability will improve the acceptance of user charging, encourage transfer between modes, and reduce operating costs.

Syncromodality, Intermodality, interoperability and integration of transport systems

A door-to-door freight and passenger transport system requires a refocus of design and operation around customer needs. This in turn should lead to a better integration between transport modes. The rapid development of ICT systems will enable big developments in the integration of information in ticketing, journey planning, and traffic and congestion management. This will enable users to make better modal decisions and foster the improvement of interoperability across networks. Improved management, operations and maintenance through the interconnectedness of mobile sensors, mobile applications and in general the opportunities offered by the Internet of Things (IoT) can be used by transport service providers, users and authorities to improve the visibility of transport processes. Innovation triggered by Blockchain technology in the supply chain and logistics would allow for a real-time planning of inventories, passenger flows, equipment and routing.

The uptake of unconventional transport systems both for freight (e.g. drones) and passengers (e.g. biking, automated vehicles) will require rethinking of intermodal nodes. Research into the optimum density of freight distribution points may be useful.

Life Cycle Optimisation

Better operational practice, combined with full exploitation of digital and control technology mean that the need for additional transport infrastructure can be reduced by better using existing infrastructure. Cooperative and automated transport, dynamic demand management, improvement of traffic management and control have high potentials to maximise asset utilisation. The infrastructure design phase often considers carbon and emissions only for the original construction phase. The carbon intensity of operation, maintenance and eventual decommissioning is not routinely considered. Transport infrastructure and energy networks are generally designed independently, yet are wholly interdependent for many years of subsequent operation.

Digital systems technology is developing rapidly, yet is not fully utilised in the planning, operation and maintenance of transport infrastructure. ICT and digital systems offer big opportunities for improved service through management of traffic flow, integration across modes, direct user charging, and for real time monitoring of asset condition. Similarly developments in vehicle technology, particularly in the automation of vehicles, offer the potential for more efficient use of infrastructure capacity and the reduction of unplanned disruption. With the growing demand for digital communication to and from moving vehicles, there will be a related demand for a much higher capacity digital infrastructure to carry the operational digital data as well as users own demands for data on the move. In most cases it will be for transport infrastructure owners to ensure that this digital capacity is provided, including the high quality secure digital infrastructure that will be needed for operating their particular systems.

The measurement of carbon expended in the construction, maintenance, and eventual deconstruction or recycling of infrastructure is un-developed. A form of energy labelling for transport infrastructure would be a useful means of helping passengers and freight shippers make informed transport decisions.

To achieve the optimum overall CO2 emissions reduction of the system, improved integration of transport infrastructure and energy systems is necessary.

Infrastructure operation

The operation of transport infrastructure is the area most affected by digital technology, and by rapid changes in demand or in required service standards. Transport infrastructure needs better resilience, whether avoiding vulnerability to single system or component failure - especially on rail systems dependent on multiple critical sub-systems - or increasing protection to planned attack. Meanwhile the impact of climate change is driving asset owners to adapt their infrastructure, particularly to increase resistance to high intensity rainfall and flooding events.

Digitalisation of public infrastructure

Digitalisation and service innovation are generating transformation across all transport domains. Within the overall Smart City paradigm, smart mobility service and technology innovations are often user-based and vehicle or infrastructure-centric. Vertical solutions need to be intelligently linked across different transport sectors to optimise infrastructure use. Sustainable integration of users, vehicles and infrastructure is a core transformation lever that has great potential for cross-sectoral optimisation and deep decarbonisation impact. Supporting innovation at the systemic – not the elemental – level can accelerate the transition to low-carbon, user-centric, smart mobility systems based on access to individual, public, shared and active mobility.

Open flow of data across infrastructure and user domains is an important enabler for smart mobility services and systems innovation; however the design, governance and maintenance of public digital infrastructure will require dedicated public resources and regulatory frameworks.

7.3. Short term research and innovation actions and outlook for research and innovation actions until 2030

Research and innovation actions can prepare the ground for future policy action. Research and innovation can in particular develop and test methodologies in the following areas:

Area of work	*SYSTEMIC ANALYSIS*	
Target	Ensure a **consideration of transport systems as a whole** for decarbonisation aims, not only for infrastructure life cycle, but also for intermodal effects.	
Action		Time horizon
✓ Develop a methodology for a systemic cost-benefit analysis, including decarbonisation objectives and costs, as well as other externalities, for all transport infrastructure projects, during the whole life cycle, including system and intermodal effects. Benefits of infrastructures should be considered at a local/regional/national and European mobility levels.		2020
✓ Gain a better understanding on carbon trade-offs between investing carbon in excess infrastructure capacity and the carbon used by traffic movements delayed by congestion or disruptions.		2020
✓ Standardize the systemic cost-benefit analysis to reach a homogeneous implementation.		2020
✓ Support the development of tools for systemic cost-benefit analysis		2020

Area of work	*TRANSPORT INFRASTRUCTURE PRICING*	
Target	Develop a methodology for a homogenous EU **carbon charging approach for all transport modes** in order to guarantee the maximum decarbonisation compatible with the fair competition and seamless integration among modes.	
Action		Time horizon
✓ Develop and test a harmonised methodology for infrastructure carbon pricing, including other environmental issues such as noise, land use, etc., as well as a potential redefinition of vehicle taxes.		2020
✓ Use of big data and activity based models to better understand users' reaction to charging in order to fine tune infrastructure pricing strategies towards encouraging decarbonisation (incl. reducing congestion) and at the same time noise reduction.		2020

Area of work	*RESILIENCE*	
Target	**Improve the capacity of transport infrastructure to withstand disruption, absorb disturbance and adapt to changing conditions under extreme circumstances**, due to climatological, man-made or other effects.	
Action		Time horizon
✓ Identify and categorize main hazards to be considered for transport infrastructure resilience, as well as organizational and technical dimension of resilience.		2020
✓ Develop and test new methodologies and tools to measure the resilience of transport infrastructure.		2030

Furthermore research and innovation actions should address technological aspects of infrastructure:

Area of work	*INTERMODALITY*	
Target	**Prepare the ground for intermodality**, synchromodality, interoperability and integration of transport systems from a customer perspective,	
Action		Time horizon
✓ Conduct an analysis of the main weaknesses and bottlenecks for a real transport integration, interoperability and intermodality, from the customer perspective; analyse the potential of synchromodality.		2020
✓ Development of demonstrators and small scale implementation, in order to show technologies and new forms of information sharing needed to improve the integration of transport systems, challenges for intermodal nodes, etc.		2020
✓ Promotion of infrastructure innovation taking into account trends in logistics: focus on new infrastructure that allows fast transhipment of modular load units.		2020

Area of work	*INFRASTRUCTURE BREAKTHROUGH*
Target	Create the **framework to allow the required infrastructure breakthrough** to face the challenge of the mobility of the future.

Action	Time horizon
✓ Develop an EU labelling system for transport infrastructure, incorporating objectives of Energy Union, based on existing EU-funded initiatives and results.	2020
✓ Ensure that Research and Innovation activities are linked with policy objectives for decarbonisation of transport infrastructure and, at the same time, still keep the European Transport Industry in its key for position competitiveness	2020
✓ Prioritize technologies for carbon capture and storage, as well as conversion of carbon in other products.	2020
✓ Provide a space for non-conventional innovation in Research Programs, including, for example, donations or crowd-funding for financing, blockchain technology applications in passenger and freight logistics.	2020
✓ Develop new contractual performance indicators, incentives, innovation, technology, etc. aiming the reduction in the number and consequence of transport accidents, considering not only infrastructure but also human behaviour.	2020

Area of work	*CAPACITY*
Target	**Maximise asset utilisation** for transport infrastructure

Action	Time horizon
✓ Develop tools for information and data collection and management to monitor the performance of the infrastructure (asset utilisation rate).	2020
✓ Develop technologies for the reliable anticipation of peak hours and effective provision of alternatives for passengers and goods, trying to balance lack of capacity in certain modes with exceeding capacity in others.	2020
✓ Support technology evolution to accelerate the rapid deployment of new business models.	2030

Area of work	*ENERGY*
Target	Facilitate a **progressive reduction of energy consumption of transport infrastructure** in the whole life cycle and from a systemic and intermodal perspective.

Action	Time horizon
✓ Improve the presence of innovative fields of work in Research Programmes, such as energy harvesting, implication of proper maintenance of road infrastructure in energy consumption and carbon production, etc.	2020
✓ Support the development of improved integration (national, regional) of transport infrastructure and energy systems.	2020

Area of work	*OPEN DATA*
Target	Facilitate the **creation of added value services** for transport stakeholders and final customers based on the collection of data from multiple sources.

Action	Time horizon
✓ Develop technology solutions for proper and effective data collection from decentralized sources, including mobile devices, and the creation of new customer-oriented services.	2020
✓ Examine how open data collection and use can be balanced with the required security issues regarding transport performance, and privacy of personal user data.	2030