



# Logistics, Energy and Mobility 2030

Meta-study for the BMWi  
ICT for Electromobility Technology Programme

Gefördert durch:



Bundesministerium  
für Wirtschaft  
und Energie

aufgrund eines Beschlusses  
des Deutschen Bundestages

IKT FÜR   
ELEKTROMOBILITÄT

Study

## **Logistics, Energy and Mobility 2030**

Meta-study for the BMWi ICT for Electromobility Technology Programme  
Berlin

### **Authors:**

**Nora Dörr**, Coordination and main author

VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V.

**Lydia Dormann**, Specialist field: Battery Technology

VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V.

**Dr Wolfgang Klebsch**, Specialist field: Hydrogen

VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V.

**Annelie Oleniczak**, Editing

VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V.

### **Technical advisors:**

**Sebastian Kosslers**, Charging infrastructure in 2030

DKE in DIN and VDE technical expert

**Florian Regnery**, Charging infrastructure in 2030

Project Manager for E-Mobility, Grid Operation in VDE FNN

### **Publisher:**

VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V.  
commissioned to perform accompanying research to ICT for Electromobility,  
a technology programme of the Federal Ministry for Economic Affairs and Energy

VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V.  
Stresemannallee 15  
60596 Frankfurt am Main  
www.vde.com

Office of Accompanying Research to ICT for Electromobility  
Bismarckstraße 33  
10625 Berlin  
nora.doerr@vde.com  
Phone: +49 151 4022 3166

### **Design:**

Kerstin Gewalt | Medien&Räume

### **Cover photo**

eyetronic / Fotolia

January 2021

# Contents

	<b>Management Abstract</b>	<b>1</b>
<b>1.</b>	<b>Introduction</b>	<b>2</b>
<b>2.</b>	<b>Drive energy – the status quo</b>	<b>4</b>
<b>3.</b>	<b>Energy sources and drive forms</b>	<b>7</b>
3.1	Battery systems for electromobility	7
3.2	Hydrogen for mobile applications	12
3.3	Developments in alternative fuels	18
3.4	Assessment of the use of fuel alternatives	22
<b>4.</b>	<b>Energy industry</b>	<b>24</b>
4.1	Energy demand 2030	24
4.2	Actors in the 2030 energy market	24
4.3	“Wasserstoff am Zug” (“Hydrogen for Trains”) – 2030 Energy Scenario	28
<b>5.</b>	<b>Charging infrastructure by 2030</b>	<b>29</b>
5.1	Electric charging technology and infrastructure	29
5.2	Charging and load management in the power grid in 2030	32
5.3	Distribution network and refuelling infrastructure for hydrogen	34
<b>6.</b>	<b>Transport – Vehicle types and operational forms</b>	<b>36</b>
<b>7.</b>	<b>Modes of transport</b>	<b>39</b>
7.1	Increase in transport capacity	39
7.2	Use of existing networks	39
<b>8.</b>	<b>Transport and logistics actors</b>	<b>41</b>
8.1	Logistics actors and their growth potential	41
8.2	Mobility service providers	42
8.3	Factors influencing future transport services	43
<b>9.</b>	<b>2030 logistics scenarios</b>	<b>44</b>
9.1	Logistics trends	44
9.2	Flybot – the flying robot for autonomous parcel deliveries: an autonomous delivery scenario of the future	44
9.3	Advertising pillar (“Litfaß”) logistics – vendor-independent locker system as urban delivery scenario	45
9.4	PC – Parcel Concierge – Bundling of parcels and customised delivery	47
9.5	Last Mile Market – the exchange for unused delivery volume in urban areas	48
9.6	DBee logistics – the multimodal rail logistics of the future	50
9.7	Starting points for sustainable logistics	51
<b>10.</b>	<b>Current trends</b>	<b>53</b>
10.1	Corona-related implications and challenges	53
10.2	Promotion of CO <sub>2</sub> -neutral transport	54
<b>11.</b>	<b>Challenges facing the ICT for Electromobility Technology Programme until 2030</b>	<b>56</b>
<b>12.</b>	<b>Outlook and conclusion</b>	<b>59</b>
	<b>List of Figures</b>	<b>60</b>

# Management Abstract

This meta-study examines possible developments in the areas of mobility, logistics and energy for urban use up to the year 2030. Social behaviour, (environmental) policy requirements and economic costs are scrutinised, as are questions of technical feasibility.

The “Logistics, Energy and Mobility 2030” meta-study has been conducted as accompanying research to the ICT for Electromobility Technology Programme of the Federal Ministry for Economic Affairs and Energy (BMWi). The aim of the programme is to promote the smart use of mobility, logistics and energy. The programme has existed (in slightly modified form) since 2010 and has funded numerous projects throughout Germany during this time.

The focus of this meta-study is the energy infrastructure that underpins electromobile, non-fossil, land-based means of transport for commercial mobility and logistics use. The time horizon for the appraisal is the year 2030.

The key results for energy:

- **Batteries** have already reached a sufficient stage of development for use in mobility and logistics. Further optimisations in manufacturing costs can be expected here as the result of economies of scale. The timing of breakthroughs in basic research is not predictable because they are shrouded in uncertainty – but if and when they do occur, they could lead to a considerable increase in capacity. This would extend the travel ranges and the number of different deployment possibilities.
- **Hydrogen** will be a flexible and technically mature drive energy for heavy goods and long-distance transport by the year 2030. The first mass production models of these vehicles will then be in use. The market ramp-up will take place from 2030 to 2050.
- Other **alternative fuels** will not be available in sufficient quantities to be used as substitutes in combustion engine vehicles by 2030.
- The **energy market** will become more heterogeneous and diverse in the future. Different drive energies will exist side-by-side in 2030. However, the fundamental transformation processes necessary for the use of batteries and hydrogen will have been initiated. As a result, new actors will enter the market and existing ones will have to adapt to the changed needs and framework conditions.

The key findings for mobility and logistics:

- **Fully autonomous vehicles** will be in use as a transport solution in individual cases in 2030.
- **Transport capacity** will increase steadily until 2030. Better use must be made of existing transport mode capacities in order to facilitate effective mobility and logistics on the basis of the present distribution networks and infrastructure.
- The nature of the **logistics actors** and **mobility service providers** will be more diverse in 2030 and their number will increase, their offerings will be largely driven by digitalisation.

In addition, scenarios have been developed for individual sub-aspects:

- The “**Wasserstoff am Zug – Energieszenario 2030**” (Hydrogen for Trains – Energy Scenario 2030) describes the cooperative use of the new drive energy by different transport modes and users;
- “**Flybot**” and “**Litfaß-Logistik**” (flybot and advertising pillar logistics) are two alternative end-customer delivery concepts based, respectively, on autonomous and automated systems;
- “**Paket-Concierge**” (Parcel Concierge) and “**Last Mile Market**” are two last-mile transport concepts. The former focuses on reducing the overall number of individual deliveries, while the latter aims at better utilisation of existing delivery capacities;
- “**DBee-Logistik**” (“DBee Logistics”) is the transport of letter and parcel shipments over long distances and includes the return of this service to the railways with the help of autonomous container solutions.

Finally, possible priorities for the future orientation of funding measures are identified. In the long term, the focus should be on enabling sustainable logistics that meet the agreed climate targets and turn corresponding political decisions into reality by means of technical solutions.

# 1. Introduction

This meta-study examines possible developments in the areas of urban mobility, logistics and energy up to the year 2030. Social behaviour, (environmental) policy requirements and economic costs are considered in addition to questions of technical feasibility.

The “Logistics, Energy and Mobility 2030” meta-study has been conducted as accompanying research to the ICT for Electromobility Technology Programme of the Federal Ministry for Economic Affairs and Energy (BMWi). The aim of the programme is to promote the smart use of mobility, logistics and energy. The programme has existed (in slightly modified form) since 2010 and has funded numerous projects throughout Germany during this time.

Electricity-based mobility and logistics link the consumption of the transport and electricity sectors (integrated energy) by requiring a selection of suitable energy sources and forms of propulsion. The latter are proving to be key issues, the technological and economic development of which are difficult to foresee (→ Figure 1).

In the area of drive energy, the importance of petrol and diesel, as the currently dominant fuels, will recede and they will yield to alternative energy sources and their

drives. Similarly, renewable energy stored in hydrogen or batteries will be a major energy source for the electric drives of the future. → Chapter 3 explores the interplay of these alternative energy sources and highlights different ways in which batteries, hydrogen and alternative fuels could develop up to the year 2030.

The shift towards electromobility in the mobility and logistics sector affects not only the underlying drive technology, but also the energy industry. Here, it is above all the established actors such as the oil companies and electricity producers who have to adapt to the changing framework conditions. They must adapt their existing concepts if they are to meet the changed demands for propulsion energy and to survive in the face of new arrivals in the market. → Chapter 4 presents the different actors and the challenges facing the energy industry.

The increasing spread of electromobility is also reflected in the growing demand for charging infrastructure. The

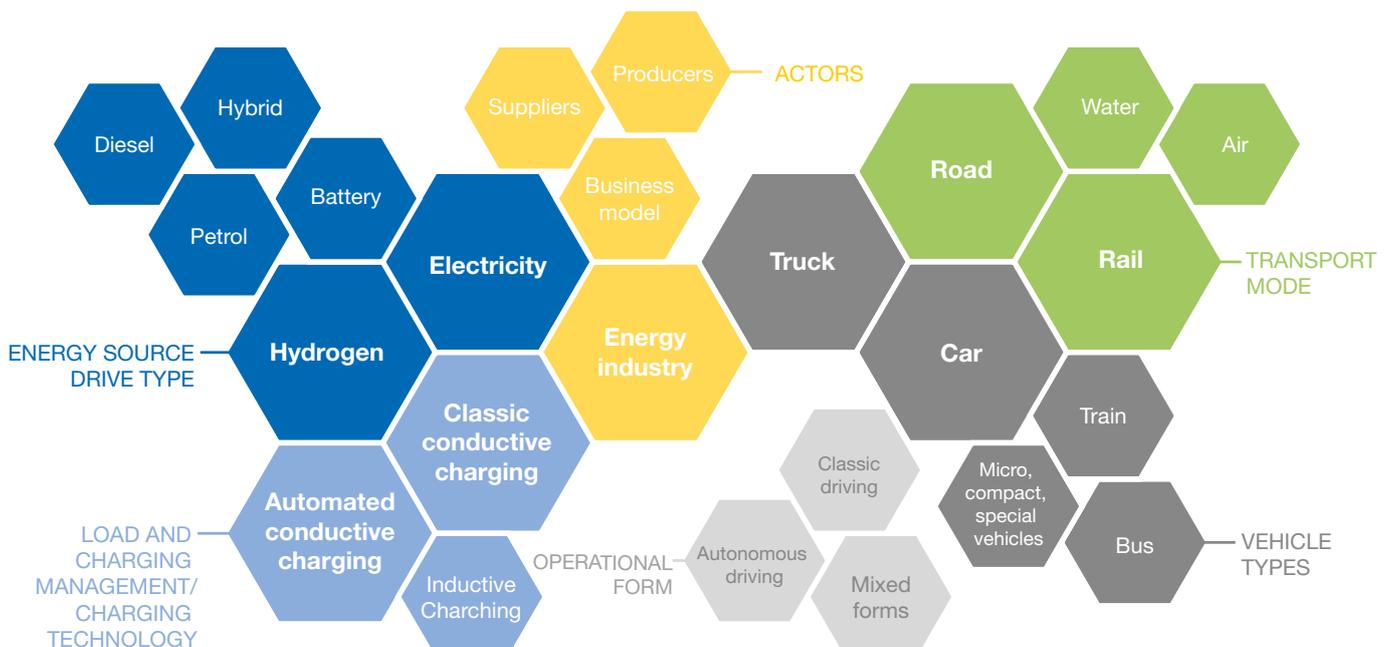


Figure 1: Key themes in 2030 meta-study

underlying charging and load management is subject to developments that cannot currently be predicted with any degree of certainty. Nevertheless, estimates can be made regarding the probable technical use. These trends are highlighted in → Chapter 5.

A range of vehicles are required for the different commercial mobility and logistics applications, the configuration of which is largely determined by the area of application. Different drive forms and energy sources can be considered for their use, depending on the individual application. → Chapter 6 therefore presents a number of exemplary vehicle types.

The different modes of transport are presented on this basis. → Chapter 7 focuses on the ways in which transport capacities can be increased and the associated use of existing transport networks.

The different constellations of the logistics and mobility actors are covered in → Chapter 8, following on from the descriptions of the various modes of transport such as rail and road. These, in turn, provide a basis for selecting the form of propulsion, the energy source and the energy industry providers.

Highlighting the resulting challenges and opportunities in each case, → Chapter 9 contains five logistics scenarios for urban areas in 2030.

A brief excursus on current trends is given in → Chapter 10, including the expected implications of corona. This is followed by a description of the potential ways in which electromobility can be promoted.

The ICT for Electromobility funding programme, has been running since 2010, and → Chapter 11 concludes by identifying the concomitant challenges that need to be addressed with technological foresight and economic sensitivity.

## 2. Drive energy – the status quo

Mobility and logistics require the use of energy. The only fuels that existed 200 years ago were the hay and oats that were consumed by horses and oxen before moving people and goods using muscle power. Fossil fuels such as coal, petrol and diesel then came to the fore with the advent of the Industrial Revolution and the associated dawn of the age of mobility. But these and other sectors contributed to climate change as a result of the increased CO<sub>2</sub> emissions.

The global community is in agreement that climate change is a threat to humanity that must be countered through a gradual shift to CO<sub>2</sub>-neutral energy sources. In her first State of the Union Address on 16 September 2020, EU Commission President Ursula von der Leyen announced a tightening of the 2050 climate targets (European Green Deal). Accounting for about one fifth of the greenhouse gases emitted, the transport sector is

currently a decisive factor and will also play a major role in achieving these goals by switching to climate-neutral energy sources and forms of propulsion.

In the Paris Climate Agreement, the EU committed itself to reducing greenhouse gas emissions in all sectors of the economy by at least 40% in comparison to the 1990 levels by 2030. In its 2030

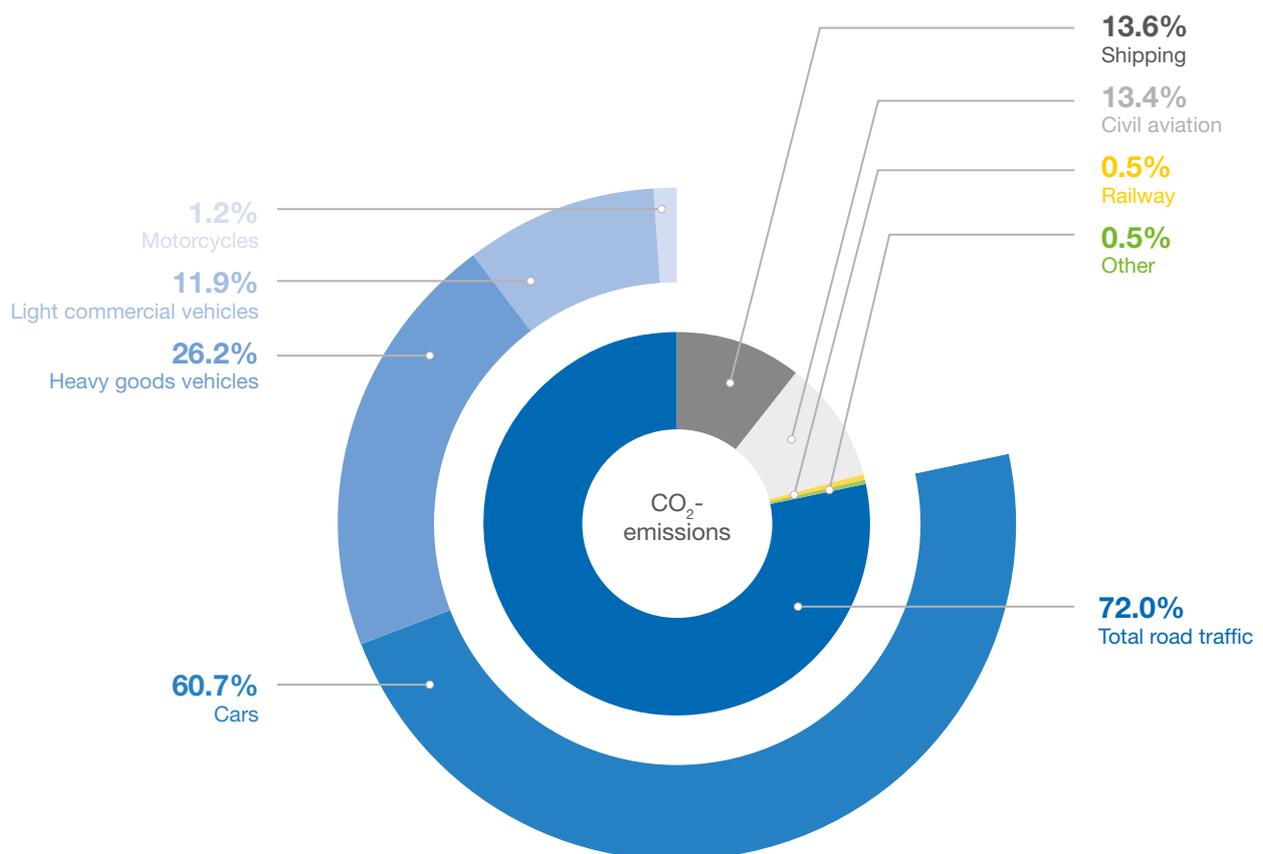


Figure 2: Potential for CO<sub>2</sub> reduction<sup>1</sup>

<sup>1</sup> <https://www.europarl.europa.eu/news/de/headlines/society/20190313STO31218/co2-emissionen-von-autos-zahlen-und-fakten-infografik> (accessed on 13.10.2020)

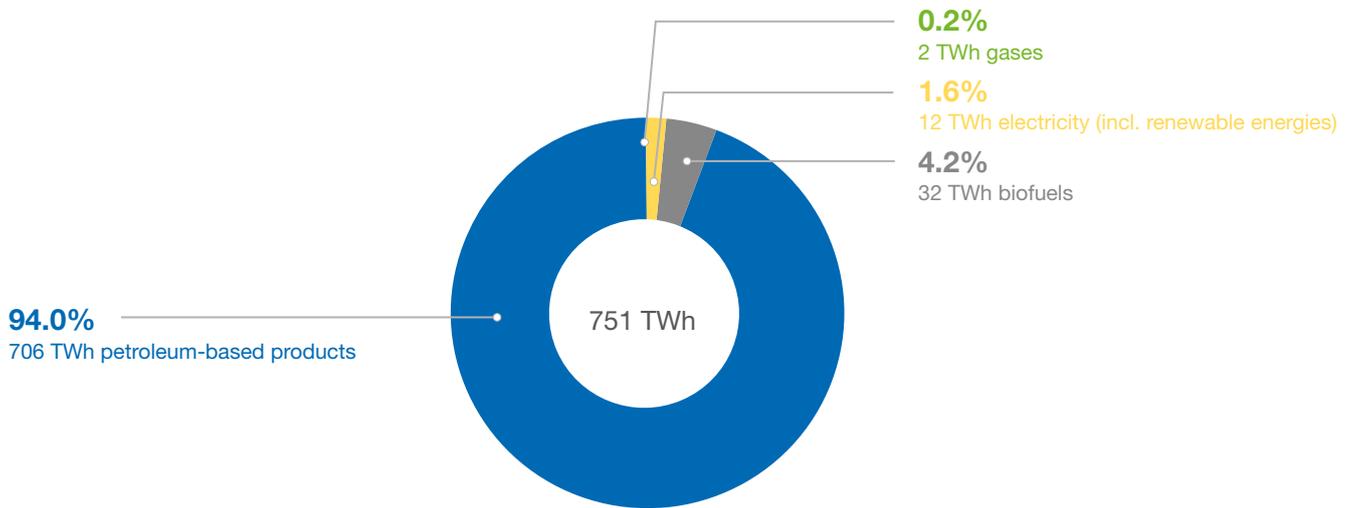


Figure 3: Final energy consumption in transport sector by energy source <sup>2</sup>

Climate Protection Programme, the German government is also aiming to reduce greenhouse gases by 55% compared to the base year 1990<sup>3</sup>. It would be possible to make the German economy completely climate-neutral by 2050 if an interim target of a 65% reduction in greenhouse gas emissions can be achieved by 2030<sup>4</sup>.

Greenhouse gas emissions in the transport sector can be reduced in particular through the widespread electrification of road transport and the use of further alternative fuels based on renewable energies (→ Figure 2).

Most of the energy currently used to power vehicles comes from fossil fuels which cause considerable long-term damage to the environment<sup>5</sup>. Petrol and diesel engines have been around for roughly one hundred years and have undergone a continual process of further development, whereas other types of drive and energy sources are still lagging behind in this respect.

Accounting for 30.1% of energy consumption, **transport** is the most energy-intensive sector in Germany. It is closely followed by industry (29.5%), private households (25.5%) as well as trade, commerce and services (15%). More than 90% of the fuels used are derived from mineral oil; pure biofuels and electricity have so far only played a minor role (→ Figure 3). Almost all the

energy used by transport is deployed to generate mechanical energy, less than half of which is converted on average in internal combustion engines to propulsion. A large proportion is lost as waste heat.<sup>6</sup>

In contrast to the other sectors, CO<sub>2</sub> emissions in the transport sector have risen since the beginning of the 1990s, both because of the rise in car and heavy goods traffic and the increasing fuel consumption of individual vehicles (→ Figure 4). Taking the EU as a whole, the transport sector is currently responsible for almost 30% of the EU's total CO<sub>2</sub> emissions. 72% of this is accounted for by road traffic. As part of its efforts to reduce CO<sub>2</sub> emissions by 2050, the EU aims to have lowered transport emissions by 60% compared to 1990 levels. So far, however, the various endeavours made by the state and the market have been counteracted by the increasing demand for mobility of the population. As a result it is becoming increasingly difficult to meet the EU's reduction target. The dwindling improvements in the fuel efficiency levels of new cars can no longer compensate for the additional CO<sub>2</sub> emissions caused by the continued growth in traffic. There was a steady decline in emissions, but newly registered cars in 2017 were emitting about 0.4 more grams of CO<sub>2</sub> per kilometre on average than in 2016. The EU's 60% target cannot be achieved through efficiency gains alone.

<sup>2</sup> <https://www.umweltbundesamt.de/daten/energie/energieverbrauch-nach-energietraegern-sektoren> (accessed on 13.10.2020)

<sup>3</sup> <https://www.bundesregierung.de/breg-de/themen/klimaschutz/klimaschutzprogramm-2030-1673578> (accessed on 1.12.2020)

<sup>4</sup> [https://static.agora-energiewende.de/fileadmin2/Projekte/2020/2020\\_10\\_KNDE/A-EW\\_195\\_KNDE\\_WEB\\_V111.pdf](https://static.agora-energiewende.de/fileadmin2/Projekte/2020/2020_10_KNDE/A-EW_195_KNDE_WEB_V111.pdf) (accessed on 1.12.2020)

<sup>5</sup> <https://www.umweltbundesamt.de/daten/energie/energieverbrauch-nach-energietraegern-sektoren> (accessed on 13.10.2020)

<sup>6</sup> <https://www.umweltbundesamt.de/daten/energie/energieverbrauch-nach-energietraegern-sektoren> (accessed on 13.10.2020)

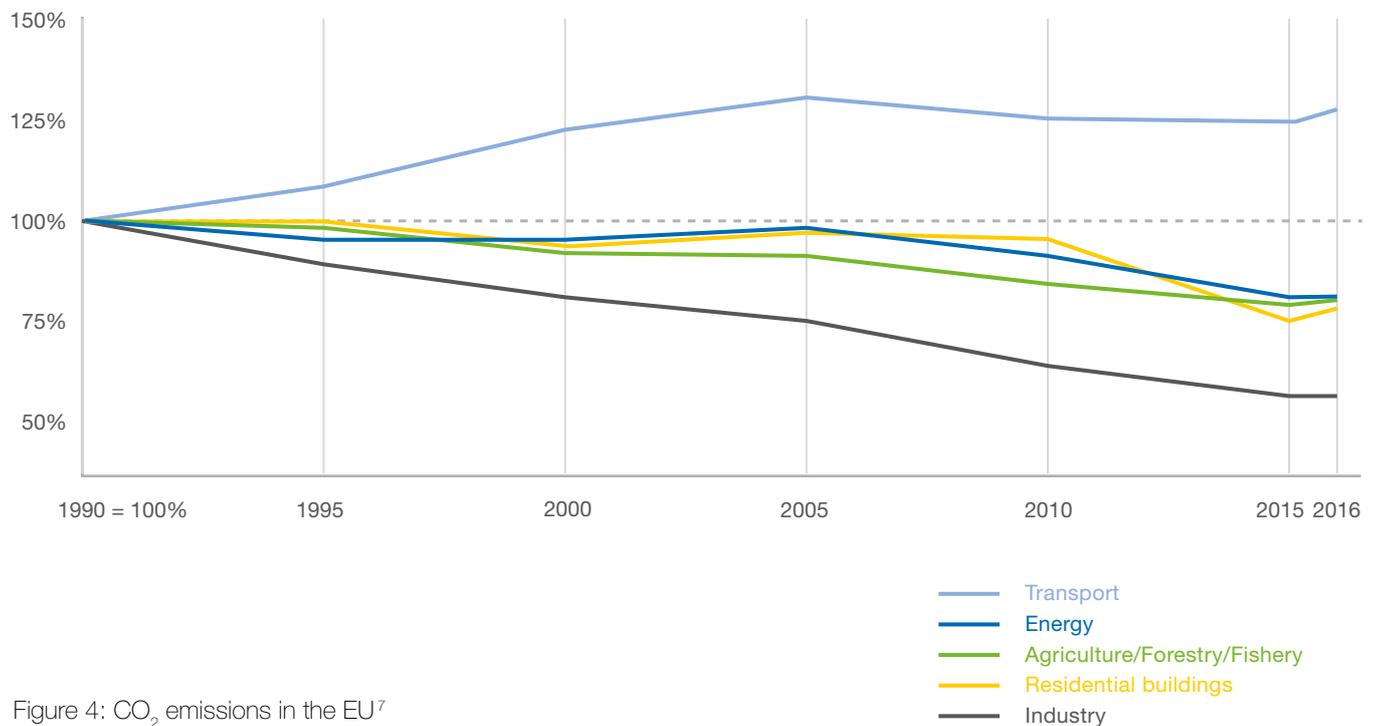


Figure 4: CO<sub>2</sub> emissions in the EU<sup>7</sup>

The EU introduced new, stricter CO<sub>2</sub> emission targets in 2019 to counteract this stagnating development. The aim of these is to reduce harmful emissions from new road vehicles. MEPs adopted a proposal to reduce CO<sub>2</sub> emissions from new trucks by 30% by 2030 compared to 2019 emission levels, for example.<sup>8</sup>

Various alternative energy sources and associated drive forms suggest themselves as means of achieving these goals. These include the existing electromobility applications on the market (charging systems, battery systems, etc.), but also hydrogen applications and alternative fuels (e-fuels, bio-fuels). A detailed consideration of these alternatives is provided in → Chapter 3.

7 <https://www.europarl.europa.eu/news/de/headlines/priorities/klimawandel/20190313STO31218/co2-emissionen-von-autos-zahlen-und-fakten-infografik> (accessed on 13.10.2020)

8 <https://www.europarl.europa.eu/news/de/headlines/priorities/klimawandel/20190313STO31218/co2-emissionen-von-autos-zahlen-und-fakten-infografik> (accessed on 13.10.2020)

# 3. Energy sources and drive forms

Three fundamentally different energy sources for future mobility are presented below. → Chapter 3.1 looks at battery systems that are suitable for use in electric vehicles. It also describes cell technologies and their respective development trends, as well as production aspects (up to the end of the first life phase), second use and recycling. This is followed in → Chapter 3.2 by an overview of hydrogen as an alternative energy source for fuel cell electric vehicles and as a key component in realising the energy transition. Finally, → Chapter 3.3 presents alternative fuels with their respective advantages and disadvantages, and gives an assessment of their development status.

## 3.1 Battery systems for electromobility

Electromobility can make a significant contribution to reducing CO<sub>2</sub> levels and to achieving long-term climate neutrality. In 2019, there were 4.79 million electric vehicles worldwide (→ Figure 1). This figure is expected to increase to 150 million by 2030<sup>9</sup>. Accumulators are used for electrification of the vehicles. These are seen as a key factor in successfully completing the mobility transition. Traction batteries currently account for about 40% of the value added and thus constitute a significant part of the cost of electric cars.<sup>10</sup> Manifold requirements apply to the batteries of electric vehicles. These include: long range, longevity with no loss of

performance, low volume and high gravimetric energy density (energy content per mass kWh/kg).

### Lithium-ion batteries

Currently, lithium-ion technology is used to drive battery-powered electric vehicles. Lithium-ion cells contain anhydrous electrolyte, which is responsible for transporting the charge between the positive and the negative electrode of the cell. To prevent short circuiting, the two electrodes are physically separated from each other by a separator – a membrane that is permeable to lithium ions.

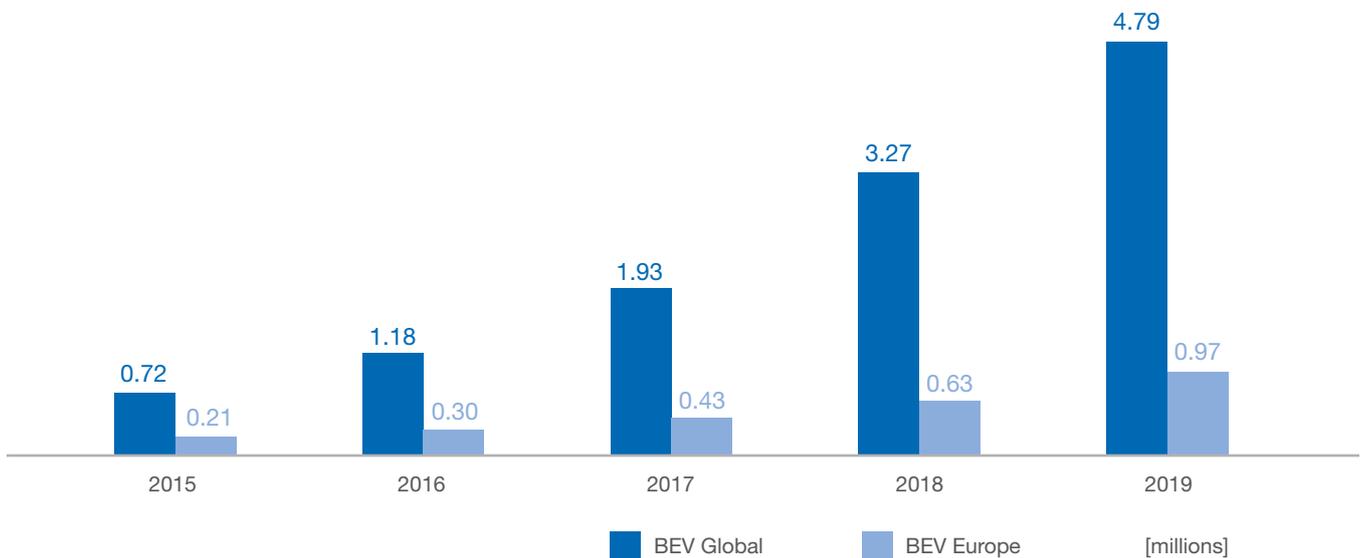


Figure 5: Number of electric vehicles – “Global” and “European”<sup>11</sup>

<sup>9</sup> <https://www.iea.org/reports/global-ev-outlook-2019> (accessed on 9.11.2020)

<sup>10</sup> <https://www.bmwi.de/Redaktion/DE/Artikel/Industrie/batteriezellfertigung.html> (accessed on 22.10.2020)

<sup>11</sup> <https://www.iea.org/> (accessed on 9.11.2020)

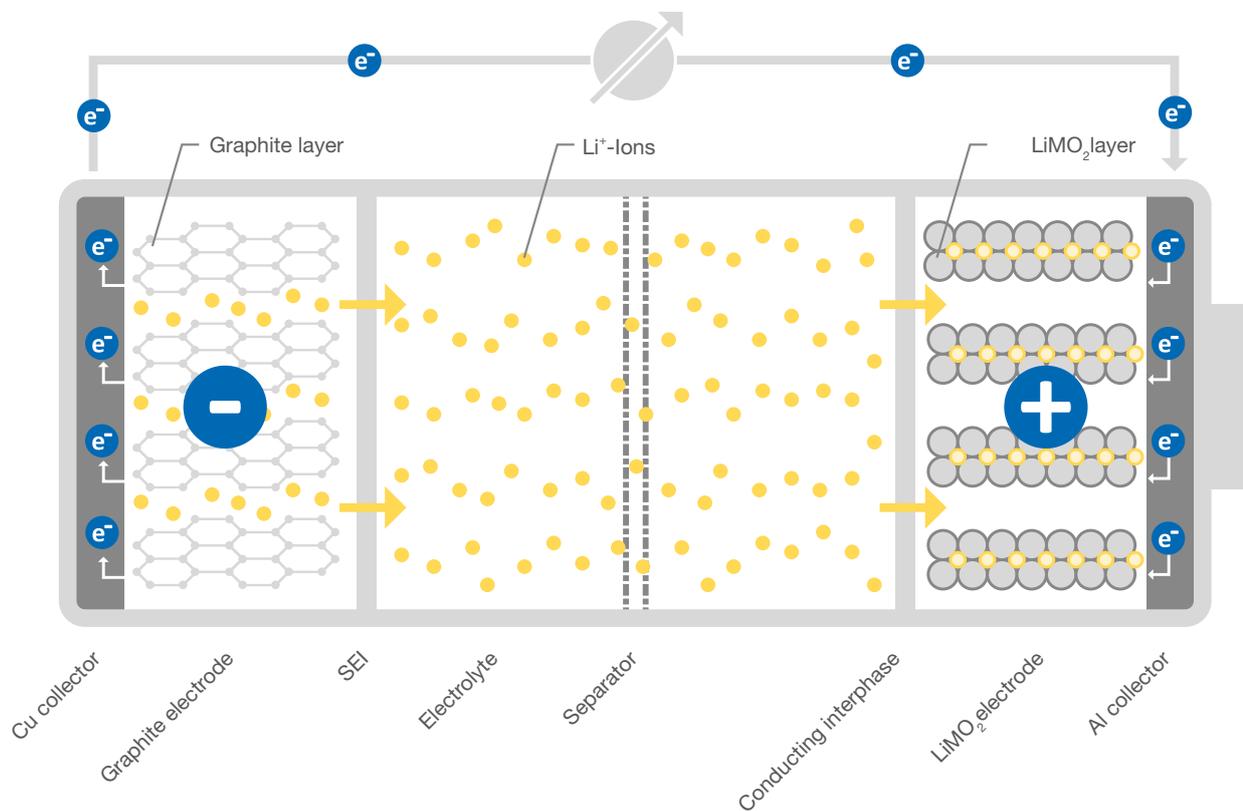


Figure 6: Structure and functioning of a lithium-ion cell during discharging<sup>12</sup>

The electrode on which the active material is chemically reduced during discharge is called the cathode of the cell. The other electrode is the anode; its active material – graphite – is oxidised during discharging.

→ Figure 6 shows the structure and function of a lithium-ion cell with the following cell components and materials:

- Lithium cobalt oxide as cathode material
- Graphite as anode material
- Mixture of organic carbonates (including ethylene carbonate) as electrolyte

Further information on lithium-ion accumulators can be found in the “Lithium-Ion Compendium”.

### Cathode material

The choice of cathode material influences the performance of the cell, including its cycle stability, energy density and costs. However, not all performance criteria can be met by a single cathode material because the individual properties are present to different extents in each cathode material. Each application also has its own criteria for the cathode material.

Cathode materials containing cobalt are widely used in electromobility. Lithium nickel cobalt aluminium (NCA) is a stable combination with a high energy and power density. Lithium nickel manganese cobalt (NMC) exhibits similarly strong compositional stability as NCA, but is more durable. Many electric car manufacturers rely on the use of NMC batteries. Cathodes with a high nickel content are increasing their share of the market. The greater the nickel content, the higher the energy density, i.e. the amount of storable energy. Nickel is also cheaper than cobalt. However, the higher the nickel content, the lower the cycle stability.

12 Compendium: Li-ion batteries in the BMWi ICT for Electromobility II funding programme: Smart Car – Smart Grid – Smart Traffic (July 2015)

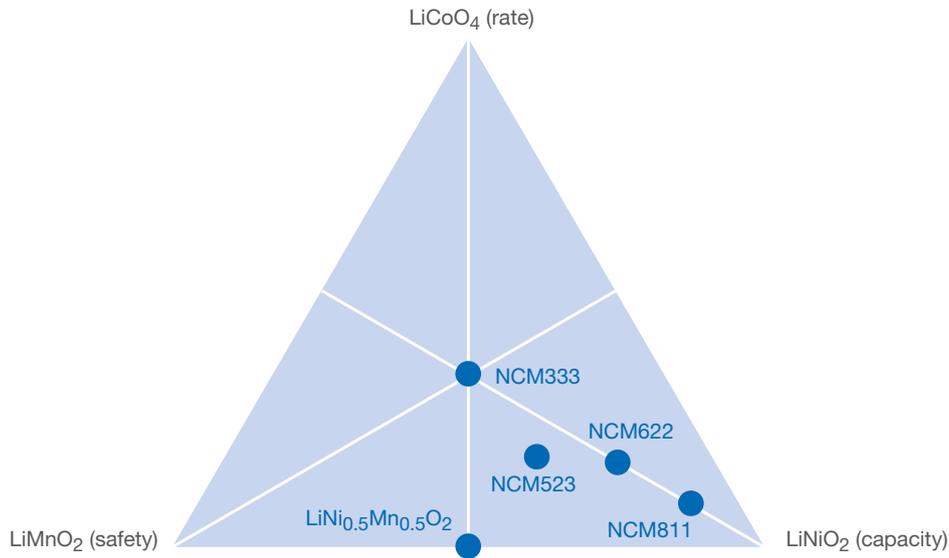


Figure 7: Phase diagram of mixtures of the transition metals Ni, Co and Mn

Batteries with a nickel-manganese-cobalt ratio of 6 : 2 : 2 (NMC-622), 5 : 3 : 2 (NMC-532) are already in use and work is now underway to make the leap to the 8 : 1 : 1 (NMC-811) variant.

Any shift in the ratios in favour of one particular characteristic comes at the expense of the others. This relationship is illustrated in the phase diagram in → Figure 7. For example, nickel-rich material such as NCM-811 has the advantage of a significantly higher energy density (capacity), but has a clear disadvantage in terms of cycle capability (rate) and safety. In the long term, the high nickel content causes the crystal structure of the material to decompose, thus reducing its capacity, i.e. operational life. Other relevant mixtures essentially line up along the scale of compromise between “rate” and “safety”.<sup>13</sup>

### Anode material

The anode of the lithium-ion cell consists of a copper foil and a layer of carbon or lithium-alloy material. The lithium ions needed to deliver the power are stored in this during charging. Graphite anodes are common because they exhibit low electrode potential and low volume expansion during the intercalation of lithium ions.<sup>14</sup>

Metallic lithium is currently mainly used as an anode for the production of primary (non-rechargeable) batteries. In the future, this anode material will also be used for the production of secondary (rechargeable) batteries. Metallic lithium has a high energy and power density but also a low weight. The challenge arises in the charging process. The danger is that the lithium does not deposit evenly on the anode, and that dendrites form on the anode surface. Dendrites are nail-shaped structures which – in simplified terms – can pierce the separator and create a short circuit. Researchers are trying to find a solution that facilitates the use of lithium metal, for example by combining it with ceramic solids.

Other possibilities include silicon-based anode materials. Silicon-carbon composites, for example, combine graphite with certain amounts of silicon. The volumetric energy density (energy per volume) of silicon is significantly higher than that of graphite. However, the use of silicon as anode material is still under development, as the change in volume of the anode during the charging and discharging process still poses difficulties.

### Research into future battery technologies

Recent years have seen an increase in research into both existing as well as fundamentally new materials.

<sup>13</sup> VDE Study Battery systems for multiple units; 27 August 2018

<sup>14</sup> Compendium: Li-ion batteries in the BMWi ICT for Electromobility II funding programme: Smart Car – Smart Grid – Smart Traffic. Basics, evaluation criteria, laws and standards: July 2015

The following battery technologies offer an insight into the further development of current lithium-ion technologies and new cell chemistries.

In lithium-sulfur batteries, the cathode consists of a mixture of sulfur and carbon. Sulfur is a non-conductive material, which is why it is embedded in a conductive graphite lattice. The electrolyte is an organic solvent containing conducting salts, or a solid-state electrolyte. The anode material consists of lithium metal. The advantages of lithium-sulfur batteries are their potentially high gravimetric energy densities (W/kg)<sup>15</sup> and the low raw material costs of sulfur. The disadvantages include the low volumetric energy density (W/l)<sup>16</sup>, the lower power compared to commercial lithium-ion batteries, and the short battery life. This is why they are not used in today's electric vehicles and more research is needed.

Research is also being carried out on lithium-air batteries at present. The anode consists of metallic lithium, the electrolyte of a solid-state electrolyte or a conducting salt containing lithium ions, and the cathode of an air-permeable, nanoporous carbon lattice. The oxygen required for the reaction is taken from the air. The high electrochemical potential of lithium means that the system theoretically offers high gravimetric energy densities (up to 900 Wh/l and 450 Wh/kg)<sup>17</sup>. Lack of cycle stability and high voltage losses during charging are challenges that require further development work.

The aim of the development work on solid-state batteries is to be able to use solid polymeric, hybrid or ceramic electrolytes. The electrodes, too, consist of a solid material, e.g. lithium metal anode, and a high-energy cathode. In addition to increased safety, these are characterised by their high cycle stability and energy density. The energy density of the cell can be increased by combining new anode materials, for example lithium metal with a solid-state electrolyte. In practical terms, however, the corresponding production processes have yet to be defined. Use in the field of electromobility is not expected before 2030.<sup>18</sup>

## Battery cell production

Asian manufacturers are currently ahead of the German cell manufacturers in terms of knowledge surrounding the development of lithium-ion batteries. In order to reduce dependence on the Asian market, the Federal Government, the federal states and German industry are investing increasing amounts in developing cell production know-how.<sup>19</sup> Research results are to be transferred from the laboratory to a pilot production plant and ultimately to industrial series production. The aim is to create a research and production landscape in which the electric vehicle industry can manufacture batteries economically and ecologically. → Figure 8 provides an overview of the planned cell manufacturers in Germany.

Price and quality are key factors in achieving competitive cells from Germany.

In order to optimise production costs, the experts at the Fraunhofer Institute for Systems and Innovation Research ISI recommend an in-depth "[...] assessment of manufacturing (incl. cost optimisation at the different stages of the value chain) and upscaling of production as well as cost reductions through standardisation [...]".<sup>20</sup> The target for 2030 is a price of around 100 euros per kilowatt hour of battery energy content. At the end of 2020, one kilowatt hour still cost around 200 euros.

In the future, the EU is set to provide a great deal of support for competitive battery cell production and thus also for the entire value chain in Europe. The resolution passed on 9.12.2019 means that up to 3.2 billion euros of funding will be made available in the participating countries (Germany, France, Italy, Poland, Belgium, Sweden, Finland). Germany is eligible for up to 1.25 billion euros (funding limit) which can be injected as permissible state aid. The goals include the production of innovative battery cells, both for use in vehicles and in power tools, and the development of dependable recycling processes.<sup>21, 22</sup>

15 [https://battery2030.eu/digitalAssets/861/c\\_861008-L1-k\\_roadmap-27-march.pdf](https://battery2030.eu/digitalAssets/861/c_861008-L1-k_roadmap-27-march.pdf) (accessed on 2.12.2020)

16 [https://battery2030.eu/digitalAssets/861/c\\_861008-L1-k\\_roadmap-27-march.pdf](https://battery2030.eu/digitalAssets/861/c_861008-L1-k_roadmap-27-march.pdf) (accessed on 2.12.2020)

17 [https://battery2030.eu/digitalAssets/861/c\\_861008-L1-k\\_roadmap-27-march.pdf](https://battery2030.eu/digitalAssets/861/c_861008-L1-k_roadmap-27-march.pdf) (accessed on 2.12.2020)

18 <https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/lib/GRM-ESEM.pdf> (accessed on 2.12.2020)

19 <https://www.bmbf.de/de/karliczek-deutschland-ist-heute-wieder-hotspot-12069.html> (accessed on 9.10.2020)

20 <https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/lib/GRM-ESEM.pdf> (accessed on 2.12.2020)

21 <https://www.automobil-produktion.de/hersteller/wirtschaft/milliardenschwere-foerderung-fuer-batteriezellfertigung-108.html> (accessed on 1.12.2020)

22 <https://www.bmw.de/Redaktion/DE/Artikel/Industrie/batteriezellfertigung.html> (accessed on 1.12.2020)

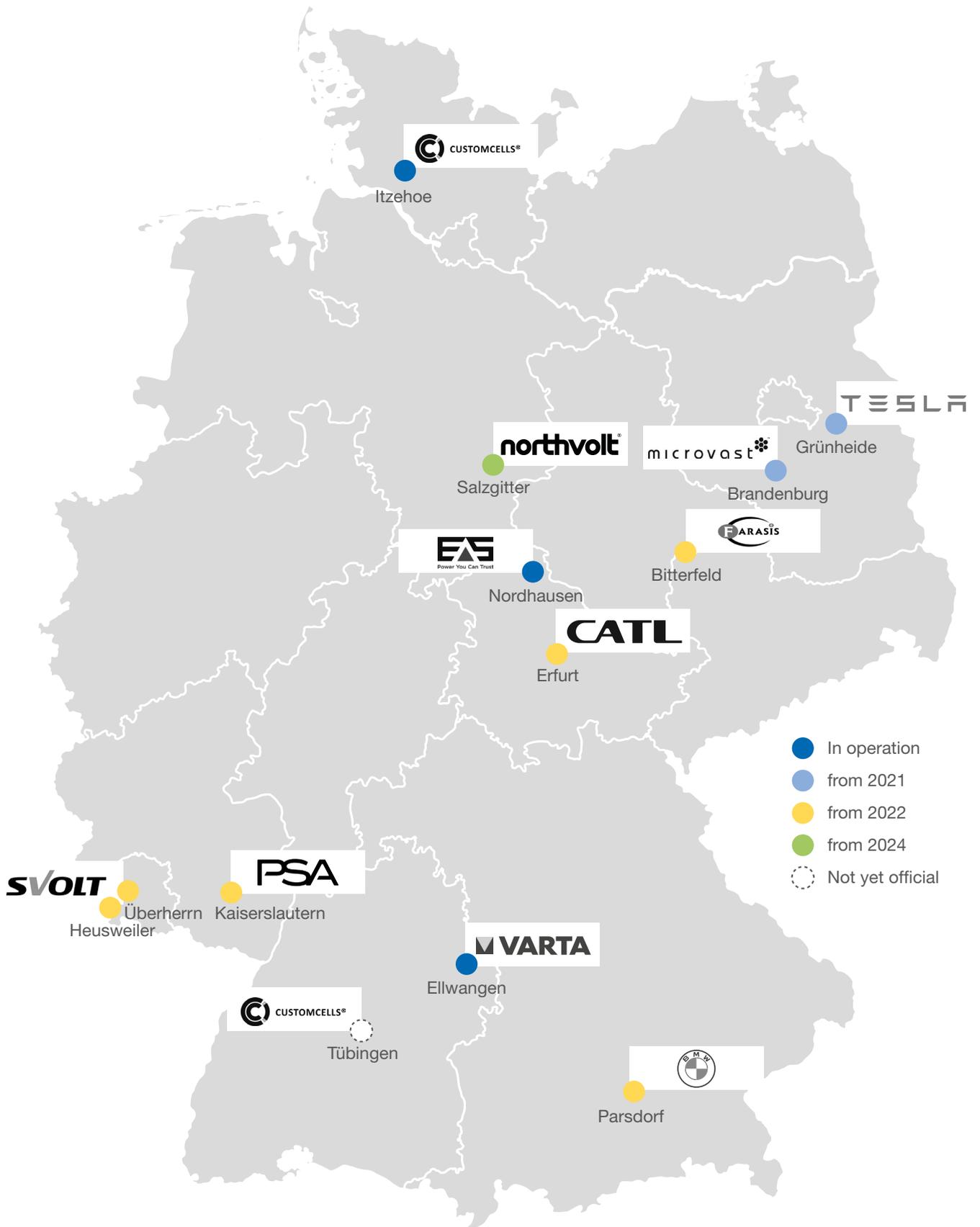


Figure 8: Battery cell production in Germany

## CO<sub>2</sub> footprint and recycling

The Federal Ministry of Economics and Technology's theses on industrial battery cell production in Germany and Europe place additional focus on the "sustainable and environmentally compatible production and disposal conditions, e.g. low CO<sub>2</sub> emissions during production [...] in the entire battery manufacturing value chain [...]".<sup>23</sup>

Many companies are striving to reduce their emissions as a consequence of the German government's climate protection goals and the growing importance of climate protection. The most important ways of achieving the climate targets include the consistent use of renewable energies, increased energy efficiency and new production processes. The CO<sub>2</sub> footprint is reduced in cases where a high proportion of renewable energy is used in production, for example in the form of self-generated electricity from solar plants or through the purchase of green electricity.

Other starting points are the supply chains, subcontractors and raw material extraction. Recycling, can be used, for example, to help reduce CO<sub>2</sub> emissions in the extraction of raw materials. As the number of electric cars increases, so does the demand for the disposal of traction batteries. The German government still has time to develop a regulatory framework. Lithium-ion batteries are characterised by their long service life (depending on usage patterns), meaning that it will be several years before the first major wave of batteries is due for recycling.

The end of the "first life" is considered to have been reached when the available capacity has fallen to 70–80% of the nominal capacity, depending on the application. This does not, however, mean that the battery has to be recycled immediately. There is then the possibility of a "second life". Here the "state of health" of the battery is examined at the end of the initial application. If this meets the second life requirements, the battery can be used in an application with a lower capacity requirement, for example as a stationary energy storage device. Only at the end of the second life is the battery submitted to the recycling process. German car manufacturers and the Federal Ministry for Economic Affairs and Energy are aiming for a 90% recycling rate. Initially, pilot plants are to be set up which will eventually be converted into industrial-scale plants in the long term.

Recycling enables valuable raw material resources such as cobalt, copper and nickel to be recovered and fed back into the recyclable material process.

## 3.2 Hydrogen for mobile applications

Due not least to the steadily growing charging infrastructure, battery-powered road and rail vehicles are gaining in acceptance, with the government and media adopting a highly optimistic stance. Hydrogen-powered vehicles, on the other hand, are still finding it difficult to attract a larger circle of users because of their apparent multiple disadvantages compared to battery-powered vehicles, such as higher energy consumption, the greater cost of the fuel, the more complex drive system, and the new refuelling infrastructure which is required. Nevertheless, in its *National Hydrogen Strategy* (NWS)<sup>24</sup>, the German government emphasises the special importance of electrolytically produced "green" hydrogen which is a prerequisite for completing the energy transition and achieving the climate targets: "green" hydrogen helps ensure very close interconnection between the main consumption areas of electricity, transport, industry and heat, i.e. *integrated energy*.

### Hydrogen and its systemic importance

Hydrogen is the most common element in the universe, accounting for 93% of all matter. It accounts for a much lower proportion of the earth's crust, however: oxygen, iron and silicon dominate here. On Earth, hydrogen occurs almost exclusively in chemically bound form – as water and hydrocarbons, organic molecules or minerals. Under *normal conditions* on Earth, free hydrogen is a colourless and odourless gas made up of diatomic molecules (H<sub>2</sub>). In the presence of open fire, sparks or embers, hydrogen gas reacts explosively with air-oxygen (O<sub>2</sub>) to form water vapour (H<sub>2</sub>O).

In the primary industry, hydrogen serves as the basis for producing substances such as ammonia, aniline, methanol and others, which are used in turn by the processing industry for the production of higher-value substances and products. In the petrochemical industry, hydrogen is needed to break down high-molecular-weight hydrocarbons in heavy oil (hydro-cracking) to produce intermediate products for the production of petrol, diesel or jet fuel. Today, these industries have an annual demand of about 19 billion standard cubic metres (Nm<sup>3</sup>) of gaseous hydrogen.<sup>25</sup>

23 [https://www.bmwi.de/Redaktion/DE/Downloads/S-T/thesen-zur-industriellen-batteriezellfertigung-in-deutschland-und-europa.pdf?\\_\\_blob=publicationFile&v=5](https://www.bmwi.de/Redaktion/DE/Downloads/S-T/thesen-zur-industriellen-batteriezellfertigung-in-deutschland-und-europa.pdf?__blob=publicationFile&v=5) (accessed on 11.10.2020)

24 <https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/die-nationale-wasserstoffstrategie.html>

25 <https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/die-nationale-wasserstoffstrategie.html>

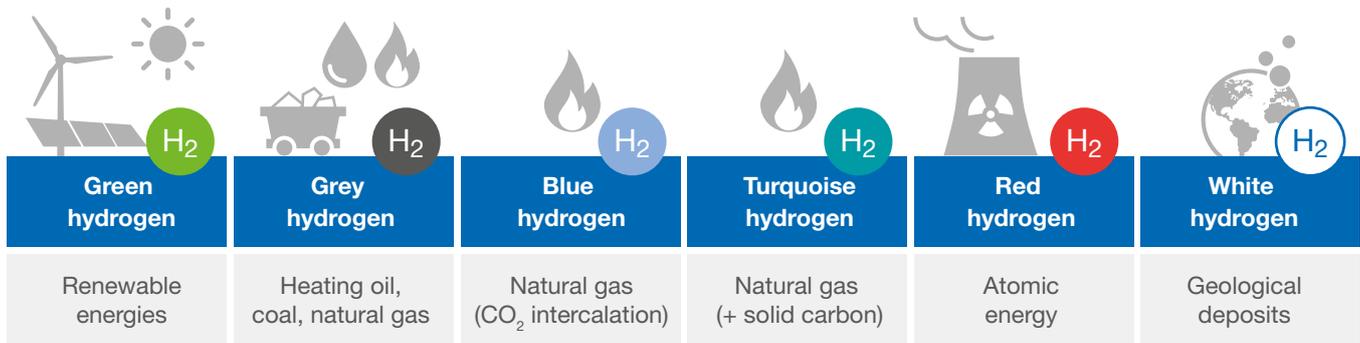


Figure 9: Colour code for basics of hydrogen production

With regard to the energy transition and climate protection, hydrogen is now crucial not only as a primary material, but also as a key energy carrier and flexible energy storage medium, especially with regard to the volatile renewable energy sources of wind and solar power. One reason for this is that hydrogen, as the lightest of all elements in the periodic table, also has one of the highest gravimetric (lower) calorific values which, at 33.33 kWh/kg, is almost three times higher than that of diesel. The volumetric calorific value of gaseous hydrogen is naturally very low at 3.00 kWh/Nm<sup>3</sup>. In order to compress as much of this gas as possible into the smallest possible space, hydrogen is nowadays greatly compressed (up to 900 bar), extremely cooled (to -252.9 °C) or dissolved in a special carrier liquid (*liquid organic hydrogen carrier*, LOHC)<sup>26</sup>.

With regard to hydrogen's function as an energy carrier and storage medium, it is important to determine *how* the hydrogen is produced: electrolysis is an obvious choice as a suitable manufacturing process. Hydrogen which is generated electrolytically using renewable electricity is also referred to as **green hydrogen**.

The hydrogen used in the primary and petrochemical industries is still produced today exclusively by steam reforming of natural gas or partial oxidation of fuel oil or coal. These processes release a large amount of climate-damaging carbon dioxide (CO<sub>2</sub>). The hydrogen produced in this way is also known as **grey hydrogen**.

Further hydrogen "colours"<sup>27</sup> can be defined (→ Figure 9), depending on the production processes used and their climate protection credentials:

in a combined process of *steam reforming* and partial oxidation known as autothermal reforming,

natural gas is converted into hydrogen and the resulting CO<sub>2</sub> is captured and stored instead of being released into the atmosphere (*carbon capture and storage*, CCS, or *carbon capture and usage*, CCU). The hydrogen can thus be produced in a climate-neutral manner in terms of its overall footprint. It is also called **blue hydrogen**.

It is also technically possible to prevent the formation of CO<sub>2</sub> entirely by pyrolysing the methane in the natural gas into gaseous hydrogen and solid carbon in a high-temperature reactor. The resulting hydrogen is also called **turquoise hydrogen**.

Another option is to use electricity from nuclear power plants for the electrolysis of water. This power, too, is generated without the formation of climate-damaging CO<sub>2</sub>. Hydrogen generated by means of *nuclear power* is **red hydrogen** and is indicated by the warning colour red.

There are also potentially usable deposits of molecular hydrogen in the upper crust of the Earth, as the French Institute for Petroleum and New Energies (IFPEN) announced in 2013.<sup>28</sup> Here, major natural hydrogen emissions occur both in the deep sea and in peridotite massifs and in certain areas of intracontinental plates – on a scale that would justify industrial use. This *naturally* occurring molecular gas is also called **white hydrogen**.

Road, rail, water and air transport must be changed over to battery or fuel cell drives, for example, or to the direct combustion of green hydrogen or synthetic fuels if the energy transition is to be effected and the

26 [http://juser.fz-juelich.de/record/861708/files/Energie\\_Umwelt\\_453.pdf](http://juser.fz-juelich.de/record/861708/files/Energie_Umwelt_453.pdf)

27 e.g. <https://www.bmbf.de/de/eine-kleine-wasserstoff-farbenlehre-10879.html>

28 [https://www.umweltdialog.de/de/wirtschaft/Innovation-Forschung/archiv/2013-05-02\\_Der-natuerliche-Wasserstoff.php](https://www.umweltdialog.de/de/wirtschaft/Innovation-Forschung/archiv/2013-05-02_Der-natuerliche-Wasserstoff.php)

climate protected in a sustainable fashion. The primary and petrochemical industries will also have to adapt to green hydrogen in the future.<sup>29</sup>

The steel industry, too, is under pressure to convert the energy used in its pig iron production from coke to hydrogen: coke is burned today in the conventional blast furnace process<sup>30</sup> in order to create the necessary heat for the reaction but also to produce carbon monoxide (CO) which is used to reduce iron ore, e.g. iron (II,III) oxide ( $\text{FeO}\cdot\text{Fe}_2\text{O}_3$ ) to pig iron (Fe). An enormous amount of climate-damaging  $\text{CO}_2$  is generated in this process. The steel industry is therefore currently seeking to introduce a new process: *direct hydrogen reduction*. Hydrogen is burned here instead of coke, with the result that only water vapour ( $\text{H}_2\text{O}$ ) is produced, instead of  $\text{CO}_2$ . However, the required heat must also be provided electrically.

The examples from the chemical and steel industries show that not only renewable electric power, but above all green hydrogen is needed to effect the energy transition and meet climate protection requirements. This is a central tenet in the German government's National Hydrogen Strategy<sup>31</sup> (NWS). There is correspondingly great pressure to produce and distribute sufficient quantities of green hydrogen. Expressed as energy units, the amount of hydrogen required annually by the primary and petrochemical industries alone is equivalent to 55 TWh (billion kWh). The NWS forecasts a total demand of 90–110 TWh (electrolysis) hydrogen for the year 2030. In the first step, 5 GW of electrolyser capacity is to be installed in Germany by 2030. This will be able to produce around 14 TWh of green hydrogen using 20 TWh of renewable electricity. A further 5 GW are to be installed in the following 5 to 10 years. Since even this large electrolyser capacity cannot produce the amount of green hydrogen needed in Germany alone, 40 GW are to be produced across Europe and an additional 40 GW in North Africa.

The following two sections present the relevant electrolysis processes and fuel cell technologies that are regarded as technical prerequisites for the production of hydrogen and its use in mobile and stationary applications.

## Electrolysers for hydrogen production

Water electrolysis allows the direct production of hydrogen and oxygen through the use of electrical energy. The device used to bring about this material conversion is called an *electrolyser*. An electrolyser essentially comprises four functional elements: cathode, anode, separator and electrolyte. The various electrolysis processes differ in their operating pressure and temperature.<sup>32</sup> The choice of electrolyte, however, is crucial for determining key properties in the process. The energy conversion efficiency of the electrolytic production of hydrogen from water is given in the literature as 70 to 80%.

In *alkaline water electrolysis*<sup>33</sup> (AEL), potassium hydroxide solution (KOH; 20–40 wt.%) serves as the electrolyte. The cathode and anode are separated by a diaphragm that allows  $\text{OH}^-$  ions to pass through for the necessary exchange of charge, while preventing the product gases from mixing. The operating temperature is in the range 40–90 °C, and current densities of 0.2–0.6 A/cm<sup>2</sup> are achieved. Compact electrolyser sizes are made possible by the high system pressures, which can be 30 bar or higher in commercial plants. One disadvantage of AEL is the slow speed with which the system reacts to changing loads in the case of volatile power supplies – such as wind and PV plants.

In *PEM (proton exchange membrane) electrolysis*<sup>34, 35, 36, 37</sup> – also called *acid electrolysis* – a special membrane is used that is permeable to protons but not to the product gases. Electrodes are attached to the front and back of the PEM. These, in turn, are connected to the positive and negative poles of the voltage source. Water is fed past the anode (positive pole). The electrolytically separated hydrogen ions (i.e. protons) are drawn through the PEM to the cathode (the negative pole), where they neutralise to form hydrogen molecules and rise as a gas. The oxygen which is produced escapes on the anode side.

In contrast to AEL, PEM electrolysis is particularly suitable for absorbing wind and solar power generated at nonregular times, as it is highly dynamic in its operation. In contrast to AEL, the product gas quality remains high even in partial-load operation. The operating temperature is between 20 and 100 °C and high current densities of up to 2 A/cm<sup>2</sup> are possible.

29 <https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/die-nationale-wasserstoffstrategie.html>

30 e.g. <https://de.wikipedia.org/wiki/Hochofen>

31 <https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/die-nationale-wasserstoffstrategie.html>

32 2017\_Book\_WasserstoffUndBrennstoffzelle.pdf (Springer: Wasserstoff und Brennstoffzellen)

33 <https://www.ffe.de/publikationen/892-elektrolyse-die-schluesseltechnologie-fuer-power-to-x>

34 <https://publications.rwth-aachen.de/record/689617/files/689617.pdf>

35 <https://new.siemens.com/global/de/produkte/energie/erneuerbare-energien/hydrogen-solutions.html#Elektrolyse>

36 <http://publications.rwth-aachen.de/record/661803/files/661803.pdf>

37 <https://igas-energy.de/technologie/pem-elektrolyse>

Efficiency levels of 68 to 72% – based on the lower calorific value – are considered achievable for entire PEM electrolysis systems.<sup>38</sup>

A disadvantage of PEM electrolysis is that its electrolyte is water interfused with free protons (ionomer), i.e. it is an acid that attacks both the electrodes as well as the catalyst coating of the membrane. Accordingly, iridium oxide ( $\text{IrO}_2$ ) is usually used for the anode material, platinum nanoparticles on carbon substrate (Pt/C) for the cathode, and pure platinum for the membrane coating.

A third pioneering electrolysis process is currently making its way from the research to the industrial application stage. This is high-temperature or *SOEC (solid oxide electrolyze cell)* electrolysis, which is based on ceramic solid electrolytes. Very high temperatures are used, so that part of the energy required for the water dissociation is drawn from the heat which is present, thus lowering the electricity requirement. For the separation of the half cells, a solid oxide is used through which oxygen ions ( $\text{O}^{2-}$ ) can diffuse. A special feature of this cell type is that its function is basically reversible, i.e. the solid oxide cell (SOC) can be used either as an electrolytic cell or as a fuel cell, depending on the operating mode. Regarding the mobile use of an SOC, it could in principle even enable the recuperation of braking energy and thus the reconversion of water into hydrogen.

## Fuel cells for electric drives

A fuel cell is a device that allows a fuel such as hydrogen to react in a controlled manner with oxygen in an electrochemical process in order to convert the energy stored in the hydrogen into electrical energy and use it, for example, to power an electric vehicle. The four main functional elements are the same as those found in electrolyzers and in batteries in general: cathode, anode, separator and electrolyte. The electrochemical properties of these determine the voltage of the cell and the current it can deliver.<sup>39</sup>

Fuel cells are suitable for stationary, portable or mobile applications, depending on the technology. Fuel cells used in vehicle powertrains must meet exacting requirements in terms of both reliability and dynamic operation: the number of operating hours and the power density are the most important criteria for

characterising fuel cells.<sup>40</sup> Similar to lithium-ion batteries or electrolyzers, fuel cells are also categorised by the electrolyte used and the operating temperature.

In the *alkaline (low-temperature) fuel cell (AFC)*, potassium hydroxide solution (KOH, 30–45 wt.%) serves as the electrolyte that is pumped through the cell. The material of the anode, where the hydrogen is oxidised, is so-called Rayney nickel; the material of the cathode, where the oxygen is reduced, is Rayney silver. Alternatively, carbon activated with precious metals can be used for the electrodes. The technology-specific low operating temperature of up to 90°C makes it necessary to use catalysts in order to achieve sufficiently high speeds in the electrochemical reaction. Relatively inexpensive catalysts can be used for AFCs. Energy conversion efficiency levels of around 60% can be achieved with this type of cell.<sup>41</sup>

The AFC purity requirements for the supplied reaction gases are extremely high because  $\text{CO}_2$  as an impurity triggers a reaction which causes the electrolyte to break down to insoluble carbonate. In order to be able to use air to provide the oxygen, the carbon dioxide must first be removed completely. In the past, these exacting requirements limited alkaline fuel cells to aviation and military use. Thanks to recent developments with regard to residual  $\text{CO}_2$  tolerance, AFCs are now also used in boat propulsion systems.

*Polymer electrolyte fuel cells (PEFCs)* – often simply called PEM fuel cells – are acidic cells. Here, protons diffuse from the anode through a thin, solid, gas-tight electrolyte membrane to the cathode, where they recombine with oxygen ions to form water. The polymer material NAFION® from DuPont is usually used for the membrane. This type of membrane must always have a specified residual moisture, i.e. be suffused with water molecules in order to realise the functional principle of the cell. This limits the operating temperature to a maximum of 100 °C, meaning that catalysts have to ensure the necessary reaction speed of the gases. The acidic environment of the cell in turn requires that the catalysts are made of platinum and the electrodes are coated with precious metals of the platinum group or their oxides to protect them from corrosion. Depending on the selected operating point, this fuel cell type achieves an electrical energy conversion efficiency rate of about 60% in practical use.<sup>42, 43</sup>

38 <https://publications.rwth-aachen.de/record/689617/files/689617.pdf>

39 Töpler, Johannes/Jochen Lehmann: Wasserstoff und Brennstoffzelle: Technologien und Marktperspektiven, New York, Vereinigte Staaten: Springer Publishing, 2017

40 [https://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/elchemenergietechnik/BWK\\_05\\_2016\\_Wasserstoff.pdf](https://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/elchemenergietechnik/BWK_05_2016_Wasserstoff.pdf)

41 Töpler/Lehmann, 2017

42 Töpler/Lehmann, 2017

43 <https://publications.rwth-aachen.de/record/689617/files/689617.pdf>

The PEM fuel cell is particularly suitable for vehicle drives which demand variable power (electric current) from the cell. The basic structure of the cell can be described as follows: the electrolyte membrane forms a *membrane electrode assembly* (MEA) with the two electrodes, which couples directly to gas diffusion layers and is connected via seals to electrode holders. These function as gas distributors or bipolar plates. PEFC cells can be produced in extremely flat form, allowing a large number of cells to be stacked on top of each other in order to generate the desired electrical voltage and to accommodate any given load.<sup>44</sup>

A third technology worth mentioning is the *solid oxide fuel cell* (SOFC). This is also called a high-temperature fuel cell, as it is operated at temperatures of 650–1000 °C. The electrolyte used here is a ceramic material that is permeable to oxygen ions (O<sup>2-</sup>) but insulating for electrons. The advantage of this type of fuel cell is that hydrogen but also hydrocarbons can be used as fuels. However, the high operating temperature requires long start-up times. For this reason, SOFCs are mainly used for stationary applications such as combined heat and power plants or for domestic energy supply at present.

### Hydrogen drives – Status quo and outlook

Green hydrogen can be burned directly to power a vehicle or is suitable for the production of synthetic fuel for conventional combustion engines, yet the established hydrogen drive concept is based on fuel cells – usually of the PEFC type. Like vehicles with traction batteries, fuel cell vehicles should also be regarded as electric vehicles. They are driven by an electric motor whose energy is provided by a fuel cell that “consumes” the hydrogen carried in a high-pressure tank and releases pure water vapour as exhaust gas (→ Figure 10).

At around 0.25 kilowatts per kilogram, the power density of PEM fuel cells is considerably lower than that of lithium-ion traction batteries (>1 kW/kg). This electrochemical disadvantage requires the fuel cell to be supported by a dynamic battery (also called a high voltage or buffer battery) during acceleration phases. The size of the battery depends on how much energy needs to be stored for acceleration and how much of the energy generated during braking is to be fed back into the battery. The greater the use made of the recuperated energy, the lower the hydrogen consumption of the vehicle.

Carrying the highly compressed hydrogen in the pressurised tank, a fuel cell vehicle can hold much more energy than could reasonably be expected from a traction battery. The resulting extended range of fuel cell vehicles is a decisive advantage over pure battery vehicles, regardless of whether they are road or rail vehicles. A fuel cell car has a range of more than 500 kilometres with a typical tank capacity of 5 kg of hydrogen. A battery-powered car with a similar range would need a battery capable of delivering at least 100 kilowatt hours. The additional energy required for dynamic driving as well as for heating, air conditioning, etc. always comes at the expense of battery range, whereas a temporary increase in hydrogen demand is easier to satisfy in fuel cell cars.

From a purely energetic point of view, however, fuel cell propulsion has a clear disadvantage. The conversion losses incurred during generation of drive current for the electric motor significantly increase the energy demand. In addition, the costs for the production and supply of green hydrogen are generally higher than those of green electricity due to the efficiency of the process.

Whether a privately used vehicle should be equipped with a battery or fuel cell depends on whether the owner mainly drives short distances and the vehicle is therefore mostly stationary, or whether he or she is a typical long-distance driver. The ratios can be differentiated much more clearly in commercial vehicles such as buses, trucks and tractors. In the case of Deutsche Post, for example, it made clear sense from a technical viewpoint to deploy battery-powered StreetScooter<sup>45</sup> parcel transporters with a range of 80 kilometres (WORK, 20 kWh) and a maximum speed of 85 km/h in DHL operation. These are small trucks in the <3.5-tonne weight class.

But what about light trucks (up to 7.5 t), medium trucks (up to 18 t) or heavy trucks (up to 40 t)? As a rule, smaller and lighter trucks are used as local transport or distribution trucks, while heavier trucks are more likely to be used for long-distance journeys. The decision between batteries and fuel cell drives in commercial vehicles depends not only on the required range (distinction between local and long-distance transport), but above all on the weight class (3.5 t / 7.5 t / 18 t / 40 t)<sup>46</sup>.

This essential dilemma can be explained most clearly using the example of heavy trucks for long-distance

44 <https://d-nb.info/991898338/34>

45 <https://de.wikipedia.org/wiki/StreetScooter>

46 <https://de.wikipedia.org/wiki/Lastkraftwagen>

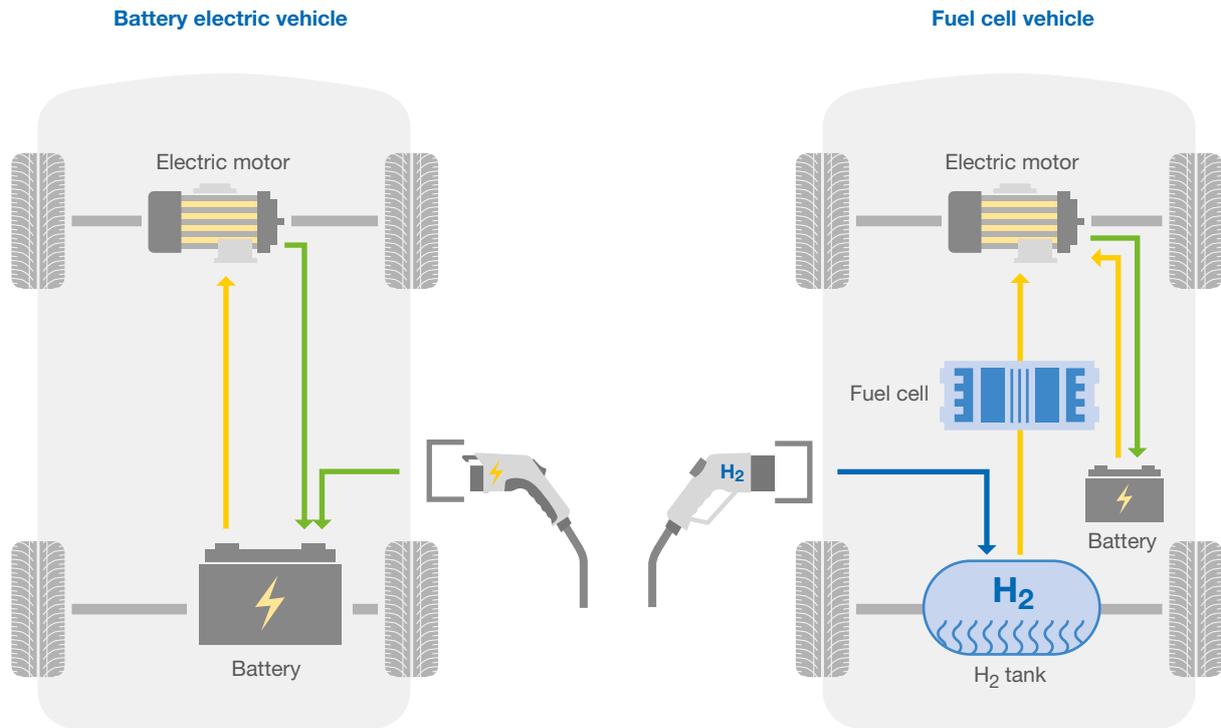


Figure 10: Comparison of drives in electric and fuel cell vehicles

transport. Today, 40-tonne trucks are mostly used on long stretches of motorway. The expected energy demand of a purely battery-powered 40 t truck can be estimated as follows on the basis of known data: the diesel consumption of a 40 t truck is around 40 litres/100 km.<sup>47</sup> A 100 t diesel multiple unit (DMU) train consumes around 100 litres/100 km.<sup>48</sup> A corresponding battery-powered electric multiple unit (BEMU) train of the same weight requires 500 kWh/100 km on average.<sup>49</sup> The energy requirement of the battery-powered 40 t truck should therefore be around 200 kWh/100 km. In practice, this would require a nominal battery size of 300 kWh. With an energy density of around 150 Wh/kg, a battery weight of at least two tonnes would have to be factored in for every 100 km of guaranteed range. A minimum range of 300 km seems reasonable bearing in mind the prescribed break times and assumed charging times. This means that a 6-tonne battery will have to be carried. This represents almost 50% of the maximum possible load of a 40 t truck.

The expected hydrogen demand of the fuel cell variant of a 40 t truck can be estimated in a similar way: a 100-tonne fuel cell multiple unit consumes about 25 kg of hydrogen (compressed to 350 bar) on a 100-kilometre journey.<sup>50</sup> Transferred proportionately to the truck, this corresponds to a consumption of around 10 kg-H<sub>2</sub>/100 km. The tanks of heavy, long-distance diesel trucks hold up to 1,000 litres. An equivalent amount of hydrogen compressed at 350 bar would weigh 31.5 kilograms. With this amount of hydrogen in the tank, the fuel cell version would already have a range of 320 kilometres. Of course, the fuel cell stack and the buffer battery also add to the weight and have their own individual space requirements. However, the size and weight of the fuel cell stack do not correlate with the range, only with the power requirements of the vehicle. The same applies to the buffer battery. A tentative generalisation can therefore be made: the heavier the vehicle and the greater the distance to be covered, the more persuasive the arguments for

47 [https://www.webfleet.com/de\\_de/webfleet/blog/so-viel-kraftstoff-verbrauchen-lkw/#:~:text=Mit%20der%20Fahrzeuggr%C3%B6%C3%9Fe%20steigt%20auch,25%20Liter%20pro%20100%20Kilometer](https://www.webfleet.com/de_de/webfleet/blog/so-viel-kraftstoff-verbrauchen-lkw/#:~:text=Mit%20der%20Fahrzeuggr%C3%B6%C3%9Fe%20steigt%20auch,25%20Liter%20pro%20100%20Kilometer)

48 <https://www.vde.com/resource/blob/1979350/a41e9c3559af76fee9c91befbc1e9216/studie-klimaneutrale-alternative-zu-dieseltriebzuegen-data.pdf> (accessed on 2.12.2020)

49 <https://www.vde.com/resource/blob/1979350/a41e9c3559af76fee9c91befbc1e9216/studie-klimaneutrale-alternative-zu-dieseltriebzuegen-data.pdf> (accessed on 2.12.2020)

50 <https://www.vde.com/resource/blob/1979350/a41e9c3559af76fee9c91befbc1e9216/studie-klimaneutrale-alternative-zu-dieseltriebzuegen-data.pdf> (accessed on 2.12.2020)

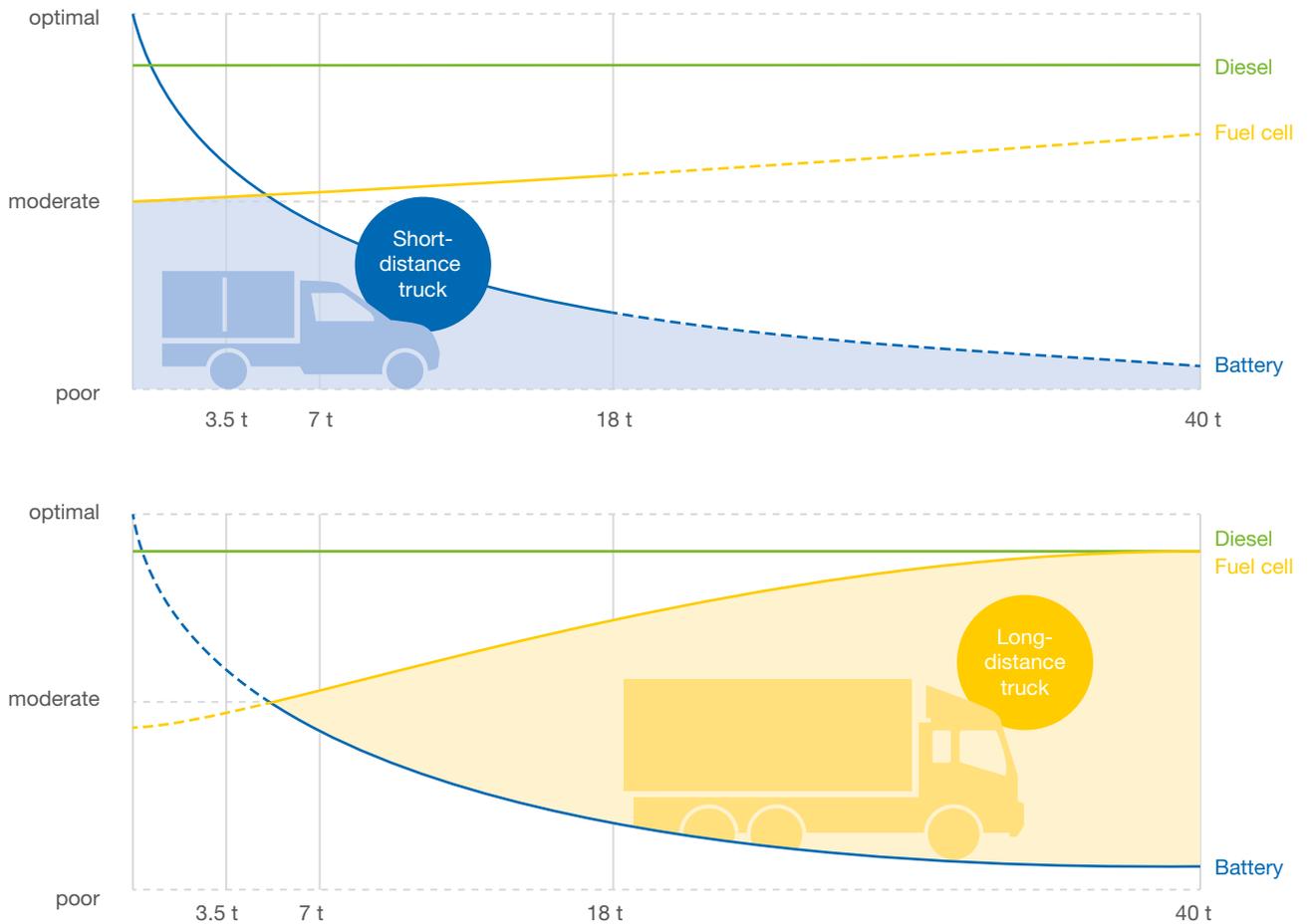


Figure 11: Battery versus hydrogen fuel cell: Application scenarios in vehicle drives

using a fuel cell (plus buffer battery) instead of a pure battery drive. → Figure 11 illustrates this for trucks in local and long-distance traffic.

100 kW fuel cell stacks are used in cars, while 400 kW are required in fuel cell multiple units. Here, the stacks must be kept at a specified optimum temperature. It therefore follows that fuel cell performance in vehicles cannot simply be increased ad infinitum. There will be a limit above which direct combustion of the hydrogen or the use of synthetic green diesel make more sense.

### 3.3 Developments in alternative fuels

Alternatives to the mineral oil-based fuels of diesel, petrol or jet fuel commonly used today include electric power and hydrogen, as used in battery or fuel cell-powered vehicles. These energy sources are only sustainable in environmental terms if they are based on renewable energies. The same applies to alternative fuels, which are intended to replace the current mineral oil-based fuels.

**Alternative fuels** include fossil fuels such as natural gas or LPG as well as biofuels based on biogenic energy sources and so-called e-fuels (→ Figure 12). Electricity-based fuels, power and primary materials are produced using PtX ("Power-to-X", i.e. conversion of electricity into any substance) processes. They are also referred to as power fuels or solar fuels. Hydrogen produced from electricity is also a fuel when used in fuel cell vehicles. Hydrogen, like batteries, can therefore be used as a storage medium for electricity.

Alternative fuels based on **fossil energy sources** such as oil or natural gas are not a sustainable alternative in terms of CO<sub>2</sub> avoidance. This first group of different conventional fuels emits different amounts of greenhouse gases per kilometre driven, depending on the energy density, consumption and chemical properties. This

Methane, which is an essential component of natural gas or biogas, also acts as a greenhouse gas: its effect is even 20 to 25 times more harmful than that of CO<sub>2</sub>. Significant quantities of it are released as a volatile gas during manufacture, transport and use.

results in considerable levels of CO<sub>2</sub> emissions<sup>51, 52</sup> (→ Figure 12). Fossil fuels therefore have no place in future efforts to achieve ecologically sustainable mobility.

The second group of alternative fuels is **biogenic fuels**. Based on biogenic energy sources, they are only ecologically (and socially) sustainable if the cultivation of the plants in question does not compete with the agricultural and forestry use of areas previously intended for food crops. Numerous renewable raw materials are available as feedstock for biofuels. The fruits of the plants are usually used for the production of first-generation biofuels (vegetable oil, bio-diesel and ethanol) due to their high sugar, starch and oil content. The rest of these first biofuel plants has a much lower energy density and can be used as animal feed.

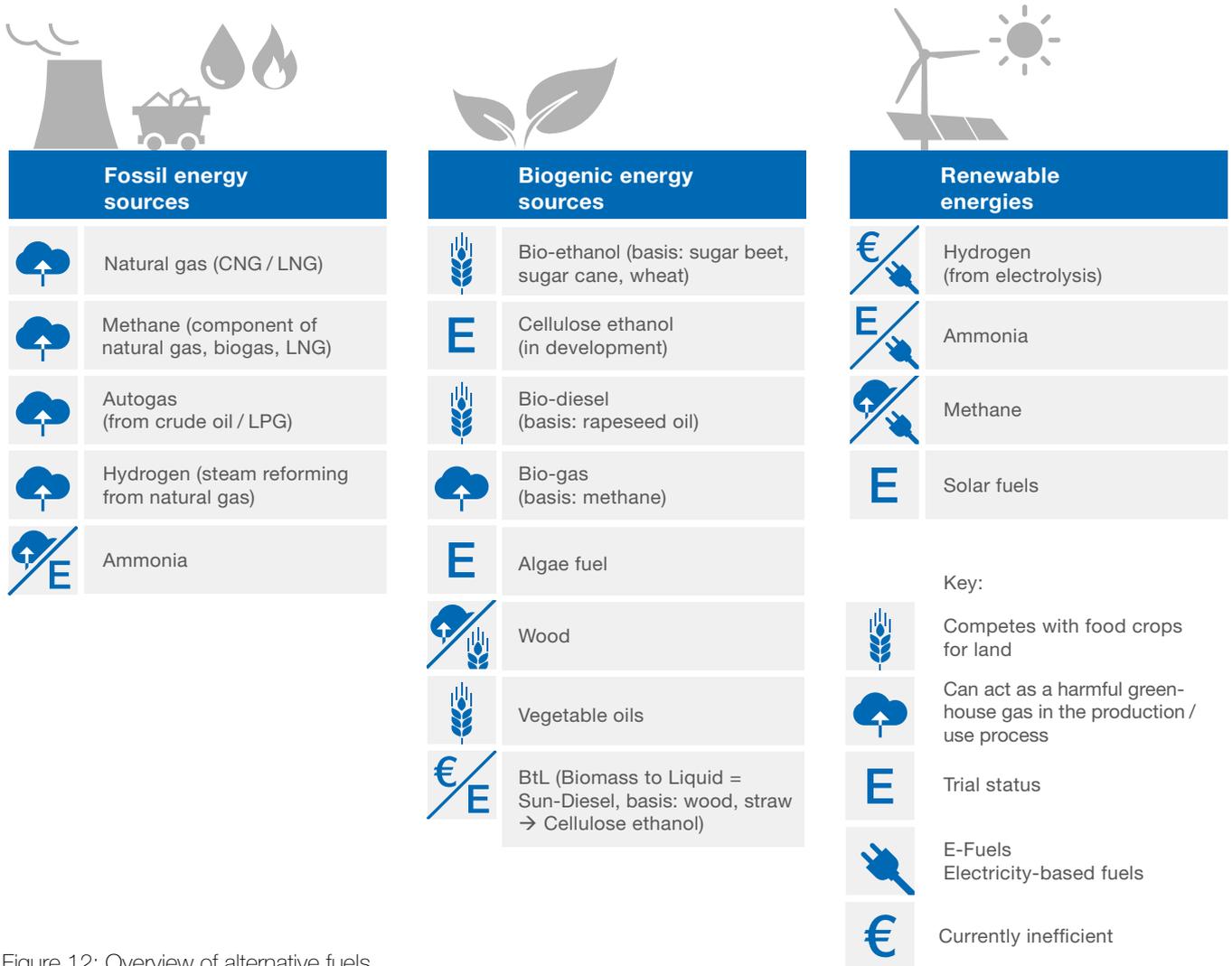


Figure 12: Overview of alternative fuels

51 <https://www.wiwo.de/finanzen/steuern-recht/benzin-gas-diesel-mit-welchem-sprit-autofahrer-am-meisten-sparen-koennen/19514990.html> (accessed on 8.7.2020)

52 <https://www.autobild.de/artikel/erdgas-vs.-benzin-test-13039493.html> (accessed on 8.7.2020)



## Closed Carbon Cycle MOBILITY

TU Bergakademie Freiberg has joined forces with Chemieanlagenbau Chemnitz GmbH (CAC) to conduct research into production processes for synthetic fuels as part of the “C3 Mobility” project funded by the Federal Ministry for Economic Affairs and Energy (BMWi).

Synthetic petrol is produced from so-called biomethanol. Biomethanol can be produced from carbon dioxide, water and electricity, but also from waste and using hydrogen produced from renewable sources. The availability of sufficient amounts of electrical energy is a prerequisite. No fossil fuels are therefore required to make this synthetic petrol.

The synthesis plant had produced its first batch of 16,000 litres of synthetic petrol by the end of 2019. A second trial is planned for 2020, in which 15 to 25 m<sup>3</sup> of non-fossil petrol will be produced.

The entire process is still at the development stage, and process parameters need to be further optimised. The process is still a long way from being ready for large-scale production or industrial application.<sup>53</sup>

The second generation of biofuels uses all components of the plant to an equal extent. However, converting the plants into ethanol in particular is currently not economically viable. Even by 2030, these fuels are unlikely to be widely available on the (end) consumer market. Cellulosic ethanol will probably remain a niche or transitional product.

The use of pure biogenic fuels has so far been reserved for a few exemplary applications. Bioethanol is used as a mandatory additive in E5 and E10 fuels. There is basically no nationwide market for biodiesel as a pure fuel<sup>54</sup>. The first CO<sub>2</sub>-neutral long-haul flight using sustainably produced biomass jet fuel (Sustainable Aviation Fuel, SAF) was operated by DB Schenker and Lufthansa Cargo on the Frankfurt-Shanghai route at the end of November 2020. DB Schenker plans to introduce regular CO<sub>2</sub>-neutral flights to its service portfolio with the 2021 flight schedule. For both companies, however, biogenic fuels only represent an intermediate step towards the use of electricity-based fuels.<sup>55</sup>

**Electricity-based fuels** are the third group of alternative fuels. Provided that the underlying electricity is generated from renewable energies, as is the case with solar fuels, these can also be classified as a “green” alternative.

**Solar fuels** are obtained by means of electrochemical, photochemical and thermochemical processes. The three methods are used to generate a solar synthesis gas (or syngas). This is a mixture of hydrogen and carbon monoxide which can then be converted into jet fuel.<sup>56</sup> Industrial scale usage of these is probably not realistic by 2030, even though several research projects (for example SOLAR-JET<sup>57</sup>, HyFlexFuel<sup>58</sup> or SUN-to-LIQUID<sup>59</sup>) have shown the fundamental feasibility. For example, the SOLAR-JET project yielded a total of only about 700 litres and the SUN-to-LIQUID project produced about 8400 litres of biofuel. As a point of reference: a short-haul flight consumes about 6 litres of jet fuel per 100 passenger kilometres. On a Frankfurt-Berlin flight in a corresponding aircraft (A320 class, 200 passengers), this adds up to approx. 4,880 litres. Solar fuels are therefore still in the early stages of development<sup>60, 61</sup> and at the

53 [http://www1.bayern.landtag.de/www/ElanTextAblage\\_WP18/Drucksachen/Schriftliche%20Anfragen/18\\_0005631.pdf](http://www1.bayern.landtag.de/www/ElanTextAblage_WP18/Drucksachen/Schriftliche%20Anfragen/18_0005631.pdf)

54 [https://de.wikipedia.org/wiki/Biodiesel#cite\\_note-105](https://de.wikipedia.org/wiki/Biodiesel#cite_note-105) (accessed on 11.12.2020)

55 <https://www.dbschenker.com/qa-en/about/press/corporate-news/co2-neutral-freight-flights-670152> (accessed on 11.12.2020)

56 <https://www.bauhaus-luftfahrt.net/de/topthema/solare-kraftstoffe/> (accessed on 2.12.2020)

57 <https://cordis.europa.eu/project/id/285098> (accessed on 9.7.2020)

58 <https://www.hyflexfuel.eu/technologies/> (accessed on 9.7.2020)

59 <https://www.sun-to-liquid.eu/page/home.php> (accessed on 9.7.2020)

60 <https://www.bauhaus-luftfahrt.net/de/topthema/solare-kraftstoffe/> (accessed on 9.7.2020)

61 <https://www.nordlb.de/de/research/download/1638/direct/> (accessed on 12.12.2020)

Fuel	Petrol	Diesel	Autogas (LPG)	Natural gas (CNG)	Energy stored in hydrogen *	Energy stored in electricity *
CO <sub>2</sub> emission [kg/l] <sup>62</sup>	2.32	2.65	1.79	1.63	0	0
Energy density [kwh] <sup>63, 64, 65, 66</sup>	8.8/l (~12.0 /kg)	9.9/l (~11.9 /kg)	6.8/l (~12.8 /kg)	13.3/l (~10.6–13.1 /kg)	33.3/kg	0.12–0.18/kg **
Consumption [100 km] <sup>67</sup>	8.0 l	6.4 l	9.6 l	6.0 l	1.0 kg	18.0 kWh
CO <sub>2</sub> emission [kg/100 k]	18.56	19.96	17.18	9.78	0	0

\* Use of green hydrogen or renewable energies

\*\* The energy density of the battery depends on the chemical properties

Figure 13: Comparison of conventional and alternative fuels

present time it is not possible to foresee when industrial-scale production will be possible<sup>68</sup>. DHL, for example, believes that solar fuels are not a suitable means of achieving “medium-term bridging to full electrification”<sup>69</sup>. The widespread use of e-fuels and their subgroup solar fuels as alternative fuels for logistics and mobility does not appear viable by 2030.

The BMWi’s “Energiewende im Verkehr” (“Energy Transition in Transport”) research initiative is currently carrying out fundamental work into the production and use of electricity-based fuels and the comparability of fuel costs across the various concepts within its 16 research associations and the overarching accompanying research project “BEniVer”<sup>70, 71</sup>.

Electricity-based fuels and basic materials will eventually make an important contribution to climate protection

and decarbonisation of the economy, although they will not be ready for industrial use in the immediate future, in contrast to battery and hydrogen applications. In addition to the direct use of hydrogen, they can be used in particular in energy-intensive industries as an alternative to fossil fuels. This applies in particular to transport sectors in which the direct use of electricity is expected to remain a technical challenge in the future (e.g. air and long-distance sea transport).<sup>72</sup>

62 <https://www.deutsche-handwerks-zeitung.de/kraftstoffverbrauch-in-co2-ausstoss-umrechnen/150/3097/57956> (accessed on 8.7.2020)

63 Figures per l or kg; the figures per kg for petrol, diesel, LPG, CNG may differ slightly because there are different density grades of each.

64 [https://www.linde-gas.at/de/images/1007\\_rechnen\\_sie\\_mit\\_wasserstoff\\_v110\\_tcm550-169419.pdf](https://www.linde-gas.at/de/images/1007_rechnen_sie_mit_wasserstoff_v110_tcm550-169419.pdf) (accessed on 9.7.2020)

65 <https://www.erdgas.info/erdgas-mobil/alternative-kraftstoffe/vergleich-cng-und-lpg/> (Abruf am 09.07.2020)

66 <https://www.wissenschaft.de/allgemein/energiedichte-verschiedener-kraftstoffe/> (accessed on 9.11.2020)

67 <https://www.deutsche-handwerks-zeitung.de/kraftstoffverbrauch-in-co2-ausstoss-umrechnen/150/3097/57956> (accessed on 8.7.2020)

68 <https://www.dpdhl.com/content/dam/dpdhl/de/media-center/responsibility/dpdhl-whitepaper-nachhaltige-kraftstoffe-fuer-die-logistik.pdf> (accessed on 9.7.2020)

69 <https://www.dpdhl.com/content/dam/dpdhl/de/media-center/responsibility/dpdhl-whitepaper-nachhaltige-kraftstoffe-fuer-die-logistik.pdf> (accessed on 9.7.2020)

70 [https://www.energiesystem-forschung.de/foerdern/energiewende\\_im\\_verkehr](https://www.energiesystem-forschung.de/foerdern/energiewende_im_verkehr) (accessed on 1.12.2020)

71 <https://www.bmw.de/Redaktion/DE/Pressemitteilungen/2020/11/20201103-strombasierte-kraftstoffe-der-zukunft.html> (accessed on 22.10.2020)

72 [http://www1.bayern.landtag.de/www/ElanTextAblage\\_WP18/Drucksachen/Schriftliche\\_Anfragen/18\\_0005631.pdf](http://www1.bayern.landtag.de/www/ElanTextAblage_WP18/Drucksachen/Schriftliche_Anfragen/18_0005631.pdf) (accessed on 13.10.2020)

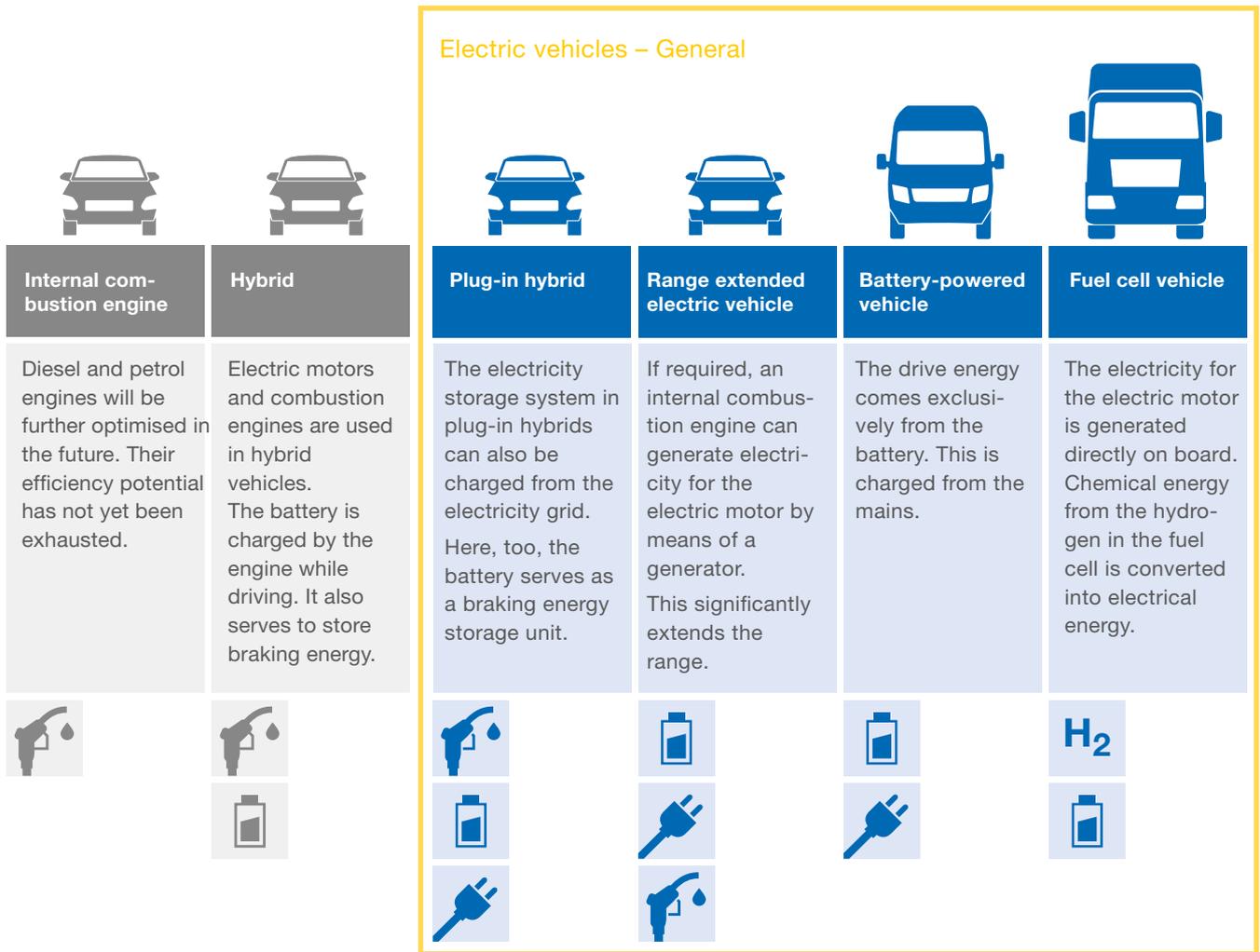


Figure 14: Drive technologies of the future (based on VDA information)<sup>73</sup>

### 3.4 Assessment of the use of fuel alternatives

If the three alternative drive energies hydrogen, battery power and alternative fuels (especially biofuels) and the associated drive technologies are compared, two specific applications can be identified in urban logistics that appear to be technologically feasible by 2030 (→ Figure 14).

#### Application: Small-volume end-customer deliveries and urban mobility

One use that can be effected with the existing and proven battery-electric drives is comparatively small-volume end-customer deliveries in urban areas. Mobility solutions for individual or combined transport in the sense

of a modal split are also already possible today with the existing electrically powered vehicles.

A number of challenges are associated with this first application. One aim is to deliver electricity via the grid which meets demand but is also systemically beneficial. At the same time, the amount of energy consumed for each individual delivery should be reduced to a minimum or optimised. And finally, the development and trialling of fundamentally alternative delivery concepts should be facilitated. Alongside these pure logistics requirements are the mobility demands of tradesmen, service providers and small businesses. Vehicles with a mixed electric drive system are also conceivable in urban areas in the form of plug-in hybrids or range-extended vehicles, for example (→ Figure 14).

<sup>73</sup> <https://www.vda.de/de/themen/innovation-und-technik/elektromobilitaet/startseite-elektromobilitaet.html>

## Application: Large-volume transportation

A further key application is large-volume deliveries for bricks-and-mortar retail outlets as well as distribution logistics between urban conurbations which require heavy goods transport. This transport demand is expected to be met by hydrogen-powered fuel cell vehicles (→ Figure 14).

If progress in battery development continues, purely battery-powered electric vehicles could conceivably also be used in heavy-goods transport. By the end of 2020, DHL will be using a specially developed 16-tonne all-battery electric truck from Volvo for urban deliveries within London.<sup>74</sup>

The joint development of a new type of battery technology called “Spatial Atom Layer Deposition” (SALD) by the German Fraunhofer Institutes and the Dutch governmental research institution The Netherlands Organisation (TNO) could contribute here. This would make the use of lighter, safer and more powerful batteries conceivable in cars, but also in trucks, mobile phones and wearables. At the moment, SALD is still in the developmental, small-series production phase. The specially founded company SALD BV (Eindhoven) is responsible for industrialisation of the process. Its use in electric vehicles is forecast for 2022/2023 at the earliest.<sup>75</sup>

The use of alternative fuels and associated drive technologies depends not only on their technological maturity, but also – as shown in the previous example – on their market availability. The energy industry, charging infrastructure and charging and load management are therefore crucial elements in making electromobile logistics and mobility possible (→ Chapter 4).

74 <https://www.dhl.com/gb-en/home/press/press-archive/2020/dhl-supply-chain-takes-to-the-road-with-uks-first-electric-16-tonne-truck.html> (accessed on 2.12.2020)

75 <https://www.chemie.de/news/1168603/weit-ueber-1-000-km-reichweite-fuer-e-autos.html> (accessed on 1.12.2020)

# 4. Energy industry

The technological transition from combustion engine to electric vehicles featuring batteries or hydrogen containers also poses great challenges for the energy industry. The established actors in the electricity market will gain further significance due to the additional demand. The oil companies, on the other hand, will have to adapt if they wish to continue to exist in business and to meet the altered needs. The total energy demand and its distribution across the various energy carriers and sources will be decisive for the energy industry of the future.

## 4.1 Energy demand 2030

Current scenarios assume that up to 40% of the world's energy demand will be covered by renewable energies in 2030. Hydropower will initially remain the world's largest source of sustainably generated electricity. However, the photovoltaic sector is showing the greatest growth overall, mainly because the production costs for photovoltaic electricity have fallen significantly. Wind power (onshore and offshore) will retain its primary role in renewable energy generation, alongside hydro and solar power. Other forms of green energy will only be supplemental.<sup>76</sup>

Demand for electricity is set to increase by about 25% within the next 10 years in Germany. Following the launch of the energy transition in the 2000s and its acceleration as a result of the decisions to phase out nuclear power (taken in 2011) and coal (taken in 2019/2020), the demand for green electricity and green hydrogen will rise sharply in all relevant consumption sectors in the future, i.e. transport, electricity, industrial process heat and building heating. At the same time, fossil fuels will gradually fade into the background. Electromobile transport will raise electricity demand by up to 64 TWh by 2050. This is a 5.8-fold increase compared to 2018. Over and above this increase, additional electricity must also be provided for production of the green hydrogen needed for this drive technology. An additional 55 TWh per year of electricity will have to be provided in order to produce the total amount of green hydrogen required in Germany across all consumption sectors. This corresponds to an additional electricity demand of approx. 8%.<sup>77</sup>

Wind and solar energy must be stored during peak periods due to the volatile nature of its generation. As already shown in → Chapter 3, electrolytically produced hydrogen is a so-called e-fuel.

## 4.2 Actors in the 2030 energy market

The key actors in the energy market, both today and in 2030, are electricity producers, electricity suppliers, electricity grid operators, etc. The volatility of the electricity market will increase in the future due to the increased feed-in of renewable energy from fluctuating sources. Photovoltaic systems feed in power depending on the position of the sun and the weather, wind turbines depending on the current weather. At the same time, there will be steady growth in the number of actors due to the gradual decentralisation of energy production. The energy market is becoming more diverse, not least due to increasing liberalisation of both demand and generation (→ Figure 15).

The energy market in 2030 is expected to be much more diverse than it is today. Sustainable solutions such as the coupling of photovoltaics or wind energy with a heat pump for the small-scale supply of several households will gain in importance.<sup>78</sup> In the towns and cities, (semi) self-sufficient solutions for tenant electricity can be expected in both old and new buildings. The different settlement structure will lead to increased numbers of users of self-generated power, possibly in combination with storage solutions, in rural areas and the catchment area of urban zones.

76 <https://www.pv-magazine.de/2020/10/13/iea-world-energy-outlook-photovoltaik-ist-die-neue-beherrschende-kraft-der-weltweiten-strommaerkte/> (accessed 21.10.2020)

77 <https://www.handelsblatt.com/unternehmen/energie/energie-steigender-energiebedarf-deutschland-droht-die-oekostrom-luecke/25385468.html?ticket=ST-561756-ljBPsnsIQUheYxks1r13-ap1> (accessed on 21.10.2020)

78 <https://enertrag.com/portal-fuer-alle-erneuerbare-energie-loesungen> (accessed on 25.10.2020)

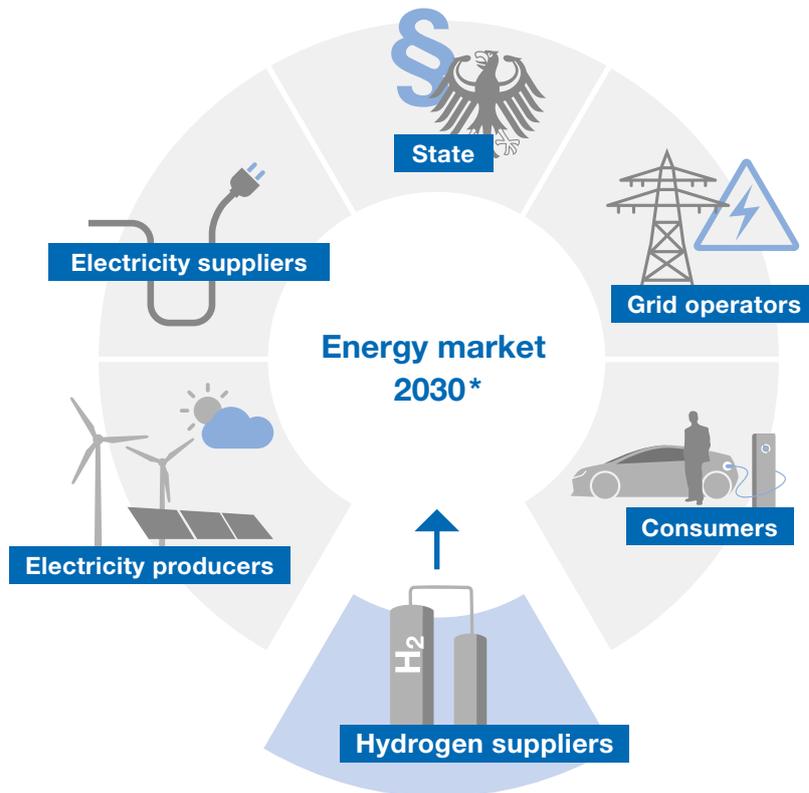


Figure 15: Energy market in 2030 (extract focusing on e-mobility, no claim to completeness)

All companies or individuals that produce electricity are **electricity producers**, regardless of the source of their generation. Upon being fed into the grid, a homogeneous product – electricity – is created. There are four large and many different medium-sized power generators in Germany. The mostly local or regional municipal utilities are also default providers (see section on electricity suppliers). In the context of the energy transition, a new type of producer has emerged in recent years: the operators of biomass, wind, hydropower or photovoltaic plants. They produce green electricity in their plants. For example, private individuals who generate green electricity via a photovoltaic system but cannot use all of it themselves and so sell it to third parties, are considered small-scale producers. The number of these micro-generators will continue to increase until 2030, by which time sideline electricity producers or private individuals will also be covering their own consumption with stationary storage solutions and passing on their excess production to third parties. The prerequisite for this is correspondingly attractive remuneration (see Renewable Energy Act info panel). The German

government has already made the use of renewable energies mandatory in new buildings through the Renewable Energies Heat Act (EEWärmeG)<sup>79</sup>. This obligation will presumably be made even more binding in the coming years and thus allow more electricity producers to enter the market. The city of Hamburg, for example, is aiming to make the use of solar systems on new buildings mandatory as early as 2022<sup>80</sup>. Commercial landlords are also affected by these regulations and will have to develop innovative solutions for their tenants and premises.

The **electricity suppliers** provide electricity to private households, companies and consumers. Their responsibilities include procuring the required quantities of electricity and submitting their daily electricity consumption forecast to the grid operator. In addition, they ensure the smooth running of the background processes, typically including the billing of all charges and levies on top of the actual energy costs. The forecast electricity quantities are procured through direct purchases from a wind farm operator or via the

79 <https://www.baunetzwissen.de/heizung/fachwissen/verordnungen-gesetze/erneuerbare-energien-waermegesetz-eewaermeg-161806> (accessed on 21.10.2020)

80 <https://www.handelsblatt.com/unternehmen/energie/erneuerbare-energien-was-eine-solarpflicht-fuer-neubauten-bringt-und-was-daran-kritisiert-wird/26252848.html?ticket=ST-1240803-KUN2t0LzurcBvDKdvzs-ap4> (accessed on 22.10.2020)

electricity exchange in Leipzig, for example. Authorised exchange participants trade electricity there. It can be purchased wholesale for a given period, such as full years, specific months, individual hours or even quarter hours. The electricity supplier acts as an intermediary between (end) customers, electricity producers and the electricity grid. It ensures that the electricity reaches the individual consumption points and can be billed. Consumer prices influence the procurement strategy and charges of the suppliers. Additional levies include the concession fee, the EEG and CHP levy and the electricity tax. In the past, electricity supply fluctuated in line with demand, but the increasingly volatile availability of renewable energies will force electricity suppliers in future to ensure that their customer's demand profile fluctuates in line with the present electricity supply. To do this, they need a detailed breakdown of the historical and current consumption values of each individual grid connection point. Accordingly, the suppliers must be able to interact closely with their customers in the future (ideally within an automated system).

**Aggregators** will increasingly emerge who integrate small producers and consumers into the flexible electricity market. Their business model is based on bringing together small generation plants, flexible consumers and storage systems and marketing them. In doing so they group together small and micro plants into tradable volumes. Until now, the rights and obligations of aggregators have not been defined in a clear and legally binding manner.<sup>81</sup> Legislation is required here if the German government wishes to promote an increasingly small-scale and decentralised energy market in the future.

The **electricity grid operators** are responsible for the grid infrastructure, i.e. for the transport routes of the electricity. They ensure that the distribution grids are stable and that the electricity which has been generated reaches the consumers. A distinction is made between transmission and distribution grid operators. The transmission grid operators are responsible for the supra-regional distribution of electricity. The distribution grid operators are responsible for regional distribution. As the interface with the customer, the electricity meter is the responsibility of the grid operator and not of the supplier. In addition, the electricity grid incorporates different voltage levels, for which the grid operators are responsible. They ensure that the electricity is transferred from the high-voltage grid via the medium-voltage grid to the low-voltage grid of the connected households. A further distinction is made between

Following the expiry of guaranteed prices under the **Renewable Energy Act (EEG)**, **the economically successful operators of solar and wind power plants now have to decide what to do with the electricity they generate.** By 2030, up to 400,000 photovoltaic systems will no longer be eligible for the guaranteed EEG subsidy. The facilities have been written off and now provide the following opportunities:

- Continued selling to the local electricity grid operator, but at far lower prices than before
- Own consumption of the electricity generated, including mandatory payment of a reduced EEG levy (expected to be 2.6 cents per kilowatt hour) – it is only possible to feed surplus into the local grid through a marketer, using appropriate measurement technology
- Direct selling to neighbours or tenants, with obligatory payment of the full EEG levy (expected to be 6.5 cents per kilowatt hour) – also only with the use of metering technology that may need to be retrofitted and is usually expensive

According to the cabinet decision of 23 September 2020, the 2021 amendment to the Renewable Energy Act does not at present explicitly provide for such small-scale user models for (partial) self-provision. The goal here – also incorporating the demands of consumer-friendliness for committed private individuals and the further promotion of e-mobility – is for producers to use as much of their own solar power as possible at the point of generation and to do so without administrative, commercial and technical obstacles. The plant operators could use the electricity themselves and sell any surplus to the neighbourhood as household electricity, for example, or to private charging stations where neighbours can charge their electric vehicles. This could also reduce the need for public charging infrastructure.<sup>82, 83</sup>

81 <https://www.energieagentur.nrw/netze/aggregatoren> (accessed on 9.11.2020)

82 <https://www.spiegel.de/wirtschaft/service/eigener-solarstrom-so-wirken-die-neuregelungen-kolumne-a-92fe28ed-767f-4db8-8be2-dd47b78e-74de> (accessed on 22.10.2020)

83 <https://www.vde.com/de/fnn/arbeitsgebiete/vom-netz-zum-system/fnn-szenario> (accessed on 27.10.2020)

competitive metering point operators and those with default responsibility. The basis for this distinction is the free choice of metering service provider enjoyed by the consumption points or connection users as stipulated in the “Gesetz zur Digitalisierung der Energiewende” (Act on the Digitalisation of the Energy Transition). The electricity grid operators must manage the demand-oriented expansion of the electricity grid to cope with the increased volatility of grid utilisation in the future. They face a dilemma here because the power lines must be designed to meet the challenges of fluctuating, renewable feed-in as effectively as possible, however expansion to maximum load is not profitable.

The **state** regulates the transport and distribution of electricity by setting the level of the corresponding charges, thereby avoiding the formation of monopolies. Accordingly, the state should be mentioned here as an additional actor in the electricity market. State-regulated transmission and distribution grid fees now account for about a quarter of electricity prices. Almost 70% of the electricity price consists of additional statutory levies in the form of state levies, taxes and surcharges (e.g. concession levy, EEG levy, grid charges, offshore liability surcharge).

Digitalisation will be a decisive factor with regard to the energy market in 2030. It will facilitate complete energy transition, as the volatility of the electricity supply necessitates measurement of supply and demand in ever shorter periods of time. Digital electricity meters can be building blocks for communication with the grid operators, allowing them to influence controllable producers or loads in order to compensate for supply fluctuations, as necessary.

### **New electricity market actors**

However, further actors are set to join the electricity energy market, and existing companies will have to undergo a transformation process. Oil companies such as BP are clearly committed to hydrogen as an alternative energy source to their current products<sup>84</sup>. This allows them to exploit their existing core competencies (such as highly complex logistics for the transport of hazardous materials) to compete in evolved and new markets. Clear corporate goals, such as serving 10%

of the sustainable hydrogen market by 2030, will help to ensure the company's long-term survival.<sup>85</sup> BP's intentions in this regard have been underlined by its construction of an electrolysis plant for the production of green hydrogen at its Lingen site. Using offshore wind turbines from the Danish operator Ørsted, the goal of the first expansion stage is to generate 50 MW of power, scaling up to 500 MW in the long term<sup>86</sup>.

Aral, the leader among the oil companies in Germany, intends to retain its dense network, but to develop it<sup>87</sup>. In future, different fuels and drive energy sources will be sold at filling stations. A model station has already been set up in Berlin (Holzmarktstraße). There, sharing options based on the Berlin app Jelbi, fast charging points and a battery replacement station have been integrated into the existing petrol station to create a “Mobility Hub”<sup>88</sup>. TOTAL also already operates a multi-energy filling station at Berlin Brandenburg Airport (BER). The hydrogen available there is produced locally using solar and wind energy<sup>89</sup>.

Other new market players include producers of technical gases such as world market leader Linde and its rival Air Liquide. They have relevant core competencies in the production and transport of hydrogen. They need to scale this up to meet the increasing demand of a larger market stemming from the wider use of fuel cell vehicles in the future.<sup>90</sup>

### **Conclusion**

In order to ensure the gradual inclusion or expansion of renewable energies in the electricity mix, the existing regulations, grid fees and also the EEG levy must be constantly updated<sup>91</sup>. Grid stability must be guaranteed, despite fluctuating feed-in. Yet it is also important to avoid the capping of power at times of high energy output through the use of flexible storage solutions such as stationary storage batteries or conversion to hydrogen. This also allows the maximum possible yield from regenerative energies to be used.

84 <https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html> (accessed on 3.11.2020)

85 Presentation given by Enno Harks, Deputy Director ; BP Europa SE ; External Affairs D at the Hydrology Online Conference (accessed on 8.10.2020)

86 <https://www.heise.de/news/Gruener-Wasserstoff-BP-und-Orsted-bauen-Elektrolyse-Anlage-in-Lingen-4953612.html> (accessed on 14.11.2020)

87 <https://www.automobil-produktion.de/zulieferer/aral-haelt-trotz-elektromobilitaet-an-tankstellennetz-fest-209.html> (accessed on 23.10.2020)

88 <https://www.aral.de/de/global/retail/presse/pressemeldungen/mobility-hub.html> (accessed on 23.10.2020)

89 <https://de.total.com/de/die-total-gruppe-deutschland/projekte-fuer-bessere-energie-deutschland/die-total-multi-energie-tankstelle-am-ber-berlin-schoenefeld> (accessed on 23.10.2020)

90 Presentation given by Dr Werner Ponikwar, Managing Director Linde Hydrogen FuelTech at the Hydrology Online Conference (accessed on 8.10.2020)

91 <https://www.bmwi.de/Redaktion/DE/Artikel/Energie/strommarkt-der-zukunft-strom-2030.html> (accessed on 25.10.2020)

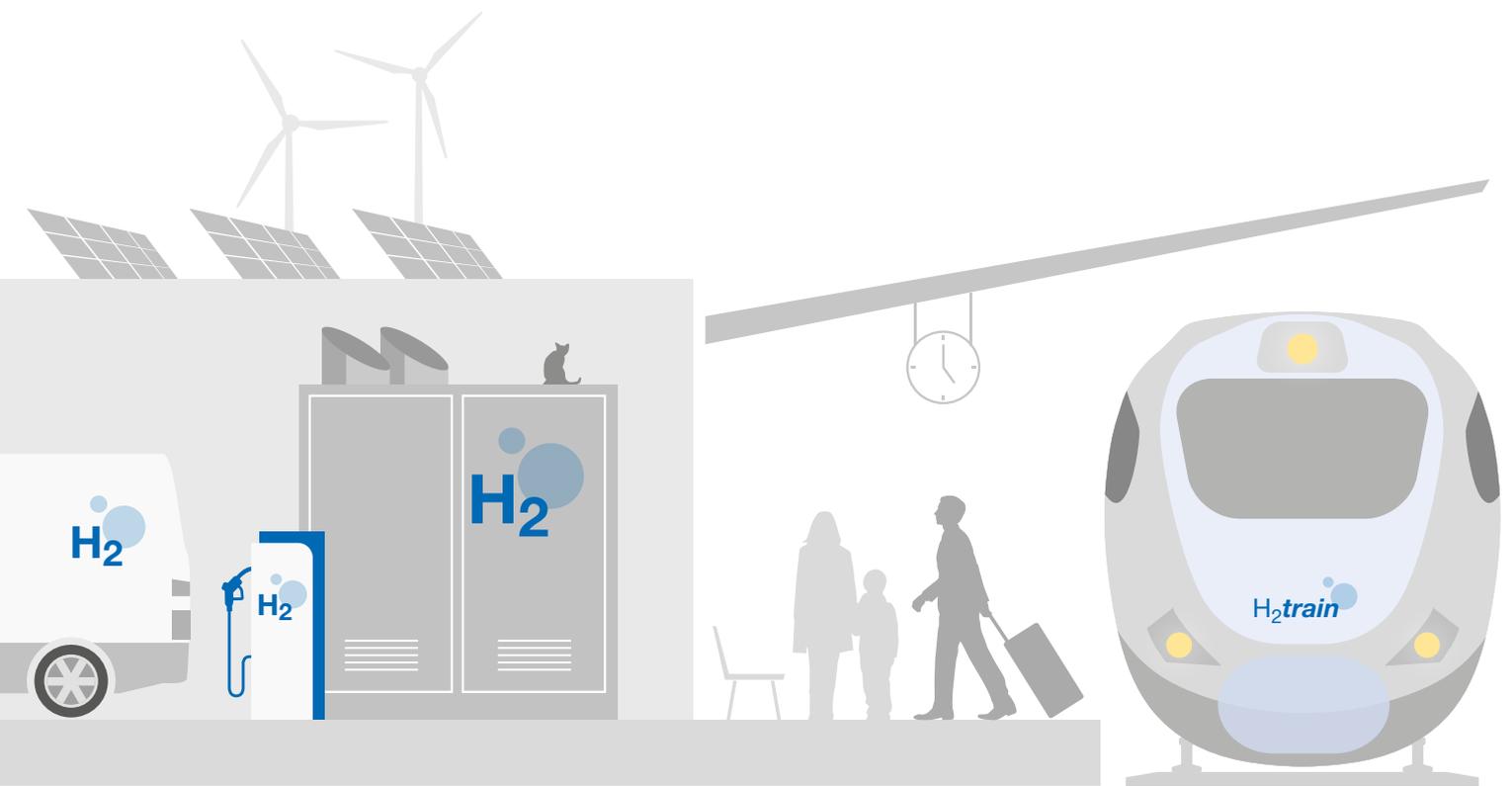


Figure 16: Energy scenario 2030

### 4.3 “Wasserstoff am Zug” (“Hydrogen for Trains”) – 2030 Energy Scenario

Multimodal transport solutions will be widely established by 2030. Both passengers and goods will cover longer distances by rail. Around 30% of the rail network in Germany is currently not electrified. Hydrogen trains will be in use as a result of the groundbreaking decisions within the DB Group taken in the early 2020s, and of the growing range of products offered by the manufacturers (Siemens, Alstom, etc.). These are steadily replacing older diesel models. With support from the Federal Ministry for Economic Affairs and Energy (BMWi), the infrastructure division of Deutsche Bahn has invested in a heavily distributed network of hydrogen filling stations to ensure that these vehicles have a ready supply of hydrogen. The filling stations will be located at regional transfer points, primarily in rural areas. The hydrogen is produced locally. Extensive photovoltaic and wind power plants will be installed on the railway’s own land for this purpose. The conversion to hydrogen takes place in mobile container solutions on site<sup>92</sup>. The containers can be quickly installed as technologically pre-developed, quasi-standardised mass-produced units. This will enable the fuel station network to be established throughout Germany

within a very short time. After being offloaded, the goods are delivered to their destination by the logistics group DB AG and its subsidiary DB Schenker and other contracted partners using their own fuel cell vehicles. The vehicles as well as the trains will be refueled with locally produced hydrogen at the respective transshipment points. (→ Figure 16). Furthermore, the fuel stations can be used by the public. This will allow local tradesmen and businesses to fill up their commercial vehicles with hydrogen there, too. The state-owned railway company has forged ahead here, with the creation of a dense network of hydrogen filling stations in a very short space of time. From an original figure of just under 100 hydrogen fuel stations<sup>93,94</sup> in 2020, the network has grown to over 1000 (including further third-party investments) within 10 years. Thus, hydrogen will then be available as an alternative fuel for numerous tasks – both for the transport and logistics services carried out by the DB Group, and for external third parties. Local production using renewable energies supports Germany’s energy autonomy. As an integral system component of a green energy market, hydrogen filling stations help to reduce CO<sub>2</sub> emissions because they support the fundamental structural transition and thus the phasing-out of nuclear power and coal.

92 <https://www.windkraft-journal.de/2018/12/31/mobile-containerloesung-zur-herstellung-von-wasserstoff-aus-windstrom/131287> (accessed on 25.10.2020)

93 <https://de.statista.com/statistik/daten/studie/820836/umfrage/anzahl-der-wasserstofftankstellen-in-deutschland/> (accessed on 25.10.2020)

94 <https://h2.live/> (accessed on 25.10.2020)

# 5. Charging infrastructure by 2030

The underlying charging technologies and the associated charging infrastructure make the drive energy available to the respective consumers and, as such, are essential building blocks in decarbonising the transport sector through electromobility. In order to ensure that the supply of electricity matches the demand, charging process management will also be necessary in 2030 and beyond due not only to the increasing number of electromobile consumers but also to the volatile feed-in arising from the increasing use of renewable energy sources.

## 5.1 Electric charging technology and infrastructure

For the first time, more e-cars could be sold worldwide in 2030 than combustion-engine cars. According to forecasts by the Boston Consulting Group, stricter regulatory requirements and falling battery costs could see electric vehicles (fully battery-powered and vehicles with hybrid drives) account for 51% of global market sales in 2030.<sup>95</sup>

A total of approximately 420,000 electric vehicles are currently registered. Of these, around 240,000 are fully battery-powered vehicles, and around 200,000 are plug-in hybrids<sup>96</sup>. The German government has set itself a target of up to 10 million registered vehicles by 2030. In order to achieve this goal, the charging infrastructure must also see corresponding development. A first milestone has been reached with approx. 21,100 publicly accessible charging points currently installed; the next step aims at one million charging points by the year 2030.<sup>97</sup> As president of the German Association of the Automotive Industry (VDA), Hildegard Müller is calling for the installation of 2,000 charging points per week in contrast to the current 200. This is the only way in which the German government's target of 1 million public charging points can be reached by 2030. At present, each charging station has to be shared by roughly 13 electric cars. Rising registration figures alongside stagnating infrastructure expansion mean that this figure will rise to 20 vehicles per charging station in spring 2021, according to VDA calculations.<sup>98</sup> However, this ignores the fact that private users with a home of their own usually install their own charging point. In addition, tenants and owners in housing communities will also be entitled to demand the installation

of charging facilities in the future. The Condominium Modernisation Act (Wohnungseigentumsmodernisierungsgesetz) represents one of the ways in which this claim was enshrined in law by the Bundesrat in autumn 2020.<sup>99</sup> This will boost the expansion of charging infrastructure not only through clear targets for the number and design of public charging points, but also through legally binding entitlement for private owners.

In terms of energy supply, there are various approaches to charging battery-powered vehicles.

“When charging with **alternating current (AC charging)**, the electrical energy from the AC grid is first transferred to the vehicle using one or three phases. The vehicle's internal charging unit is responsible for rectification and for controlling the charging of the battery. The energy transmission from the AC grid to the electric vehicle can be wired or wireless (e.g. inductive) (→ Figure 17). In most cases, the vehicle is connected to the AC grid via a suitable power supply device, e.g. an AC charging station or AC wallbox.

**DC (direct current) charging** requires the vehicle to be connected to the charging station via a charging cable. In this case, however, the charging unit is part of the charging station. Charging is controlled via a dedicated communication interface between the vehicle and the charging station.

**Conductive charging** is currently the most common method. In **inductive charging**, energy is transferred based on the transformer principle. This technology is currently still under development and is being standardised for electric vehicles. For this reason, it is not yet commercially available on a large scale.

95 <https://www.bcg.com/de-de/publications/2020/drive-electric-cars-to-the-tipping-point> (accessed on 20.10.2020)

96 <https://drehmoment.net/staat-foerdert-e-autos-doch-es-droht-eine-ladeluecke/> (accessed on 11.12.2020)

97 <https://www.bundesregierung.de/breg-de/themen/klimaschutz/ladeinfrastruktur-1692644> (accessed on 13.11.2020)

98 <https://nachrichten-online.eu/2020/11/06/elektroauto-boom-vda-fordert-2000-neue-ladepunkte-pro-woche/> (accessed on 13.11.2020)

99 <https://www.bundesregierung.de/breg-de/themen/klimaschutz/neues-wohnungseigentumsrecht-1733600> (accessed on 13.11.2020)

Battery replacement involves the removal of the discharged battery from the electric vehicle and its replacement with a charged one. This energy supply option is currently used in particular for pedelecs, e-bikes and similar vehicles, however it does not play a significant role in electric vehicles (passenger cars). There are no uniform standards for this at present. Therefore, there will be no further discussion of battery replacement here.

The definitions of **normal and fast charging** are set out in the EU Directive 2014 / 94 / EU "Deployment of Alternative Fuels Infrastructure" and are based exclusively on the amount of power used during the charging process. Thus, charging at power levels of up to 22 kW is classified as normal charging, charging at higher power is referred to as fast charging.

In addition to the classic DC charging stations delivering 50 kW and upwards, smaller DC wallboxes with outputs of 10–20 kW are gaining in popularity.<sup>100</sup>

A basic distinction is made between conductive charging, i.e. charging via a cable and plug, and inductive (contactless) charging. The charging current can be provided at stationary charging points. However, it can also be absorbed dynamically during driving: inductively by means of fixed-installation ground coils, or conductively via an overhead line or a conductor rail integrated into the track. Vehicles can also be powered by replacing the entire empty battery with a fully charged one. This can be done at stationary replacement stations, fixed points with built in infrastructure, or flexible and fluctuating replacement points (→ Figure 17).

The different charging solutions have varying degrees of complexity and can differ considerably in their technological requirements. There are also correspondingly large variations in investment costs. For example, large-scale construction in the form of overhead lines or underground charging coils in the road construction are considerably more expensive in overall economic terms than wallbox systems, which are more or less

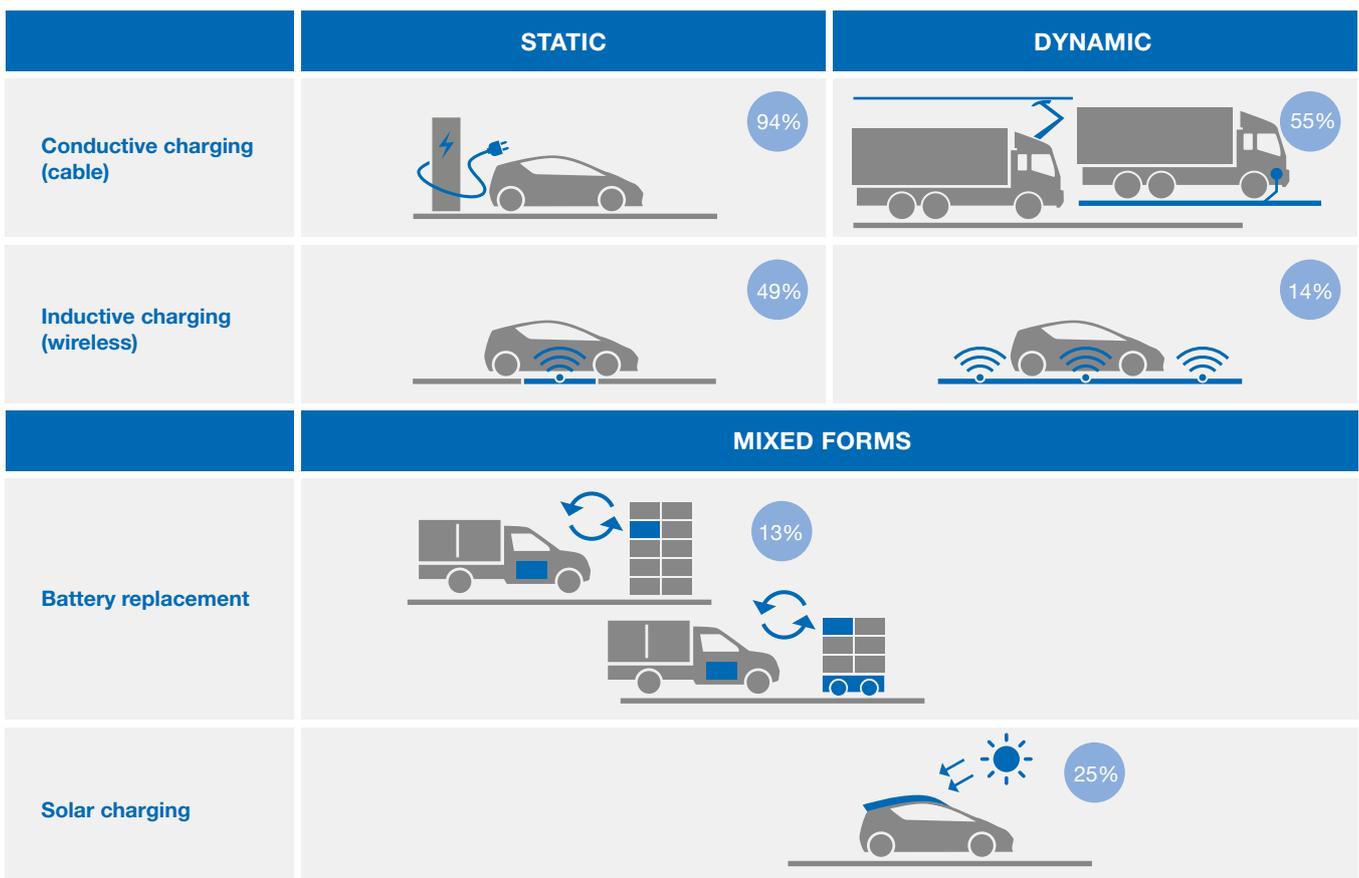


Figure 17: Probable use of charging technologies in 2030 (percentages – expert opinions<sup>101</sup>)

100 <https://www.dke.de/resource/blob/988408/a2b8e484994d628b515b56376f809e28/technischer-leitfaden-ladeinfrastruktur-elektromobil-taet---version-3-data.pdf>

101 <https://www.bayern-innovativ.de/seite/studie-ladeinfrastruktur-technologien-trends> (accessed on 26.10.2020)

	AC charging		DC charging	
Normal charging	3.7 kW	 ~35 h		
	7.4 kW			
	11 kW		10 kW	
	22 kW	 ~3.5 h	95%	20 kW
Fast charging	43 kW		28%	50 kW
High-power charging				150 kW
				250 kW
		 ~0.5 h		88%
Ultra high-power charging				300 kW
				350 kW
				450 kW
				500kW
			800kW	40%
				85%

95% Experts' assessment of probability

   ~0.5 h Charging locations (normal socket / fast charging point / ultra fast charging point);  
Calculated charging time (for 80% capacity and max. battery range 100 kWh) for Tesla S

Figure 18: Overview of charging options<sup>102, 103, 104</sup>

standardised mass-produced goods. Dynamic inductive charging is most likely to play a subordinate role in 2030. So far, the EU has not issued any uniform regulations for this and the necessary technology is comparatively expensive to produce. Replacement battery models will also remain more of a niche application. The reasons currently given for this are the lack of system standards, the high costs (at least at present) for setting up the replacement stations, restrictions in vehicle design and battery packaging, as well as the problem of battery ownership and the associated legal consequences, which still need to be clarified. Industry experts reckon that inductive charging (including assisted positioning) and manual conductive charging will be widely to universally available. These two charging op-

tions are considered cheap, efficient and comparatively easy to implement compared to the other technologies. Dynamic conductive charging will probably only become established in very specific, spatially confined areas of application such as trolley buses (→ Figure 17). Electrification of entire long-distance lines, or even of sections, would appear to be uneconomical and too prone to failure at the present time.<sup>105</sup>

It is not only the charging solutions themselves which are of importance, but also the amount of charging capacity provided and the expected development up to 2030 (→ Figure 18). Two opposing standpoints have emerged in the expectations regarding the charging power levels with widespread availability. On the one

102 <https://www.vde.com/resource/blob/1896388/8dc2a98adff3baa259dbe98ec2800bd4/fnn-hirweis--e-mobilitaet-download-data.pdf> (accessed on 13.11.2020)

103 <https://www.bayern-innovativ.de/seite/studie-ladeinfrastruktur-technologien-trends> (accessed on 26.10.2020)

104 <https://efahrer.chip.de/ladezeitenrechner> (accessed on 13.11.2020)

105 <https://www.bayern-innovativ.de/seite/studie-ladeinfrastruktur-technologien-trends> (accessed on 26.10.2020)

hand, there is the normal charging with alternating current which is comparatively slow (AC charging). This is mostly done overnight or at the workplace at a power level of up to 22 kW. On the other hand, fast high-power DC charging at rates of 150 kW or higher<sup>106</sup> will be used for ad-hoc recharging, analogous to refilling with conventional fuels.

With regard to AC charging, the higher power ranges of normal AC charging (11 or 22 kW) are likely to be widespread by 2030. The low power ranges of 3.7 and 7.4 kW are expected to be less prevalent in the future. In 2030, DC home charging solutions at comparatively low power levels will complement the typical AC charging systems used at present. DC solutions aimed primarily at private use with outputs of 22 or 24 kW<sup>107</sup>.<sup>108</sup> can also draw charging current directly from home energy systems, for example a combination of photovoltaic systems and battery buffer storage. This allows self-sufficient units to be established that can also be independent of the mains grid (→ Chapter 4).

In DC charging, widespread use in the low power range is to be expected by 2030, even though technological developments up to 800 kW are currently being explored. Medium power ranges between 150 and 350 kW are expected to be in widespread use for DC. Short charging times will also be possible for ad hoc charging and in larger charging parks thanks to fast-charging and high-power charging technologies (→ Figure 18).<sup>109</sup>

Over the next ten years, a great deal of dynamism and diversity can be expected in the development of different charging technologies and prototypes and the related interaction, communication and networking technologies for future charging infrastructures. A correspondingly broad and innovative range of products and services characterised by increasing digitalisation, data exchange and the networking of system elements can be expected in 2030. In order to meet these challenges, the technical experts of the Energietechnische Gesellschaft (ETG) in the VDE are preparing a detailed study entitled "Intelligent charging infrastructure of the future". The results are scheduled to be presented in mid-2021.

## 5.2 Charging and load management in the power grid in 2030

The charging processes and the resulting additional strain on the power grid must be managed to avoid critical situations. The volatile feed-in of 65% renewable energies (according to the Coalition Agreement on the Formation of the German Federal Government 2018) can lead to overcapacities in the electricity grid. These, in turn, can endanger grid stability. In order to maintain Germany's high grid stability in the long term<sup>110</sup>, the consumer appliances, including vehicles which are charging or are connected to the grid, must be managed. The planned 10 million electric vehicles will require 10 GW of charging capacity in 2030, which alone represents 12.5% of the total ~80 GW transmission grid load. Based on 2018 data which assumes ~83,000 e-vehicles and ~250 MW of charging capacity, this represents a forty-fold increase.<sup>111</sup> In this respect, it is imperative to conduct detailed studies and make realistic assessments of the effects of vehicle charging on the electricity grid. The influence of ad hoc and regular charging on the simultaneity factor and other performance assumptions must be determined for the future. Decisions regarding network dimensioning can then be made on the basis of empirical values and simulations. The first valid results are expected in mid-2021<sup>112</sup>.

The simultaneity factor shows the number of electrical consumers operated at full power at the same time in a household or circuit. It is offset against the total power of all relevant consumers and provides an indication of the total connection power required.

Example: A total connected load of at least 12.5 kW must be accommodated if the total power of all consumers installed in a detached house is 25 kW and the simultaneity factor is 0.5.

106 <https://www.golem.de/news/ladesaeule-tesla-bringt-supercharger-v3-mit-wasserkuehlung-in-position-1903-139870.html> (accessed on 12.11.2020)

107 [https://www.mobilityhouse.com/de\\_de/abb-dc-wallbox-ccs-chademo-24-kw-3-5-m.html](https://www.mobilityhouse.com/de_de/abb-dc-wallbox-ccs-chademo-24-kw-3-5-m.html) (accessed on 12.11.2020)

108 <https://new.abb.com/ev-charging/de/produkte/ladestationen-pkws/dc-wallbox> (accessed on 12.11.2020)

109 <https://www.bayern-innovativ.de/seite/studie-ladeinfrastruktur-technologien-trends> (accessed on 26.10.2020)

110 <https://www.vdi-nachrichten.com/technik/weniger-stromausfaelle-in-deutschland/> (accessed on 26.10.2020)

111 <https://www.vde.com/de/fnn/arbeitsgebiete/vom-netz-zum-system/fnn-szenario> (accessed on 26.10.2020)

112 <https://www.vde.com/de/fnn/aktuelles/ansturm-auf-studien-ausschreibung> (accessed on 26.10.2020)

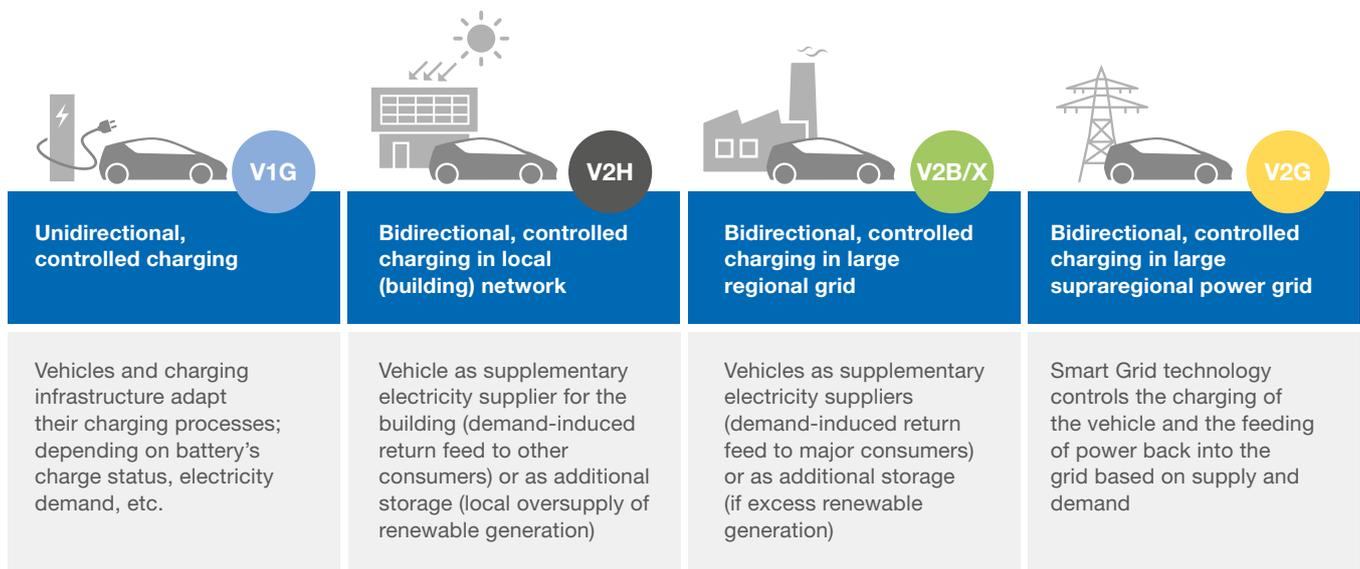


Figure 19: Concepts for consumer–power grid networking

In 2030, half of all (home) connections will be controllable, thus ensuring the flexibility and security of the electricity grid<sup>113</sup>. However, this course must be set at an early stage. The technological nature of the infrastructure in 2030 and beyond is already being shaped through the promotion of charging points in both public and private environments. This is because the wallboxes installed are designed for several thousand plug-in cycles and thus for an operational life of more than 15 years<sup>114</sup>. Uniform standards for control hardware design are therefore to be agreed in the coming months, especially on the part of the grid operators and consumers. This will facilitate intelligent load management. Existing standards must be implemented for this, thereby allowing later solutions also to be utilised internationally. These standards and prototypical implementations should then be tested in practice to verify their functionality and performance. The findings should then subsequently be passed to the national and international standardisation expert teams. This will make it possible to secure the results on a long-term basis and make them internationally marketable, thereby ensuring that installed controllable wallboxes and other electricity consumers can also be accessed externally and reached via the necessary signals. This ultimately enables grid-friendly charging and ensures problem-free interaction with other participants, such as energy management systems.

The networking of vehicles, other consumers, electricity suppliers and generators will become an important

aspect in the future with regard to the energy and mobility transition. Various technical concepts and expansion stages are conceivable for the implementation (→ Figure 19).

Currently, specific solutions are available for networking the electrical systems behind the building connection point. This allows **Vehicle2Home (V2H)** applications to be realised. The main focus here is on users optimising their own consumption. Their aim is to keep the energy suppliers' reverse feed into the grid as low as possible, as it is less economical for (private) users than consuming their own power. When electricity is produced by the solar power system, additional consumers can be activated to absorb the surplus energy. These are primarily consumers that can be switched on ad hoc, such as heat pumps, water heating systems or electric vehicles. The vehicle battery is used as a quasi stationary intermediate storage unit into which surplus solar power from the roof panels of the house is fed and, if necessary, fed back into the building and to the appliances there (e.g. cooker, washing machine, dryer). Intelligent energy management systems are needed to control the various consumers and power sources in a home network. Standardising these and thus enabling widespread application is a challenge for the future and a key topic in international standardisation. The expert teams have already created full "digital twin" data models for the interaction between electric vehicles and the energy grid and for the associated architectures (cf. IEC/TC57 and IEC/TC69).

113 <https://www.vde.com/de/fnn/arbeitsgebiete/vom-netz-zum-system/fnn-szenario> (accessed on 27.10.2020)

114 <https://www.homeandsmart.de/wallbox-elektroauto-ladestation-daheim> (Abruf am 26.10.2020)

The fully flexible use of vehicles for **Vehicle2Grid (V2G)** energy storage applications allows vehicles to be controlled for the benefit of the public power grid. The goals are: the secure and grid-friendly integration of in-feed (battery charging) and out-feed (discharging) from/to an increasingly volatile energy system (grid service at distribution grid level); system services for the transmission grid operator based on its specifications/demand; and marketing of the self-generated electricity. Before V2G can be put into practice, the technical and regulatory framework conditions for the different applications must first be defined. This applies to the smart metering system including the certified smart meter gateway as well as secure communication for, and control of, the charging and discharging of electric cars by grid and energy suppliers and new market participants such as aggregators.<sup>115</sup>

A further intelligent means of connecting the vehicle (battery) to producers, consumers and distributors of electrical energy is **Vehicle2Business (V2B)** coupling. This works in a similar way to V2H, except that larger units, i.e. companies, are coupled to multiple vehicles.

Whether and how these concepts are implemented in the future is also a question of political coordination between the various stakeholders in the system. Not least due to their legal warranty obligations, automobile manufacturers, for example, have different priorities for the battery as the central element in an e-vehicle than electricity suppliers or automated and autonomous energy management systems in buildings.

Demand-sensitive control, measurement and safety mechanisms must be established that enable the use of vehicle batteries as buffers and for storage in order to establish a flexible European electricity market by 2030 and beyond, and the use of around 10 million electric vehicles as targeted for 2030.

Interoperability and safety, which are guaranteed by international norms and standards and which ensure the future viability of the solutions developed, are central to the integration of electric vehicles and energy systems.

In terms of possible comprehensive technological preventive measures, thought should also be given to the unauthorised intervention of third parties who could exploit unintentional security gaps. Ultimately, all communication and control channels which are opened between the individual actors must also be secure.

Otherwise, a further gateway for unauthorised access is (unwittingly) opened which could do more harm than good, both to individual consumers and to the network as a whole.

### 5.3 Distribution network and refuelling infrastructure for hydrogen

Hydrogen as a drive energy can be used in gaseous or liquid form. No distribution infrastructure currently exists for either form that is suitable for everyday use. No practical network has yet been set up due to the small number of hydrogen filling stations; reliable stations only exist in seven regions (Hamburg, Berlin, Rhine-Ruhr, Frankfurt, Nuremberg, Stuttgart and Munich) and on the connecting motorways and trunk roads.

In the case of centralised hydrogen production, the electrolyser is located close to the energy plant (wind power or photovoltaics). Then the gaseous hydrogen must be transported to the users, either by pipeline or via road, rail and river. Hydrogen causes material embrittlement and corrosion. Because of this, high-purity stainless steel pipes have so far been used for the pipeline-based distribution of hydrogen; these are technologically mature. The pure transport costs are comparable to those of compressed natural gas (CNG). However, there is currently no nationwide pipeline-based supply of gaseous hydrogen. Transporting gaseous hydrogen by truck also poses challenges. Nationwide deliveries by road would further compromise the energy footprint; in addition, this requires large numbers of special corrosion-resistant tankers. Currently, the most promising solution for the distribution of centrally produced hydrogen is transportation in supra-insulated tankers. The hydrogen must be liquefied for this. However, this process requires a further 20% on top of the initial energy. Alternatively, the decentralised production of gaseous hydrogen close to the consumers is also conceivable. This would eliminate the need for transportation. However, this is offset by the increased space requirements and higher production costs associated with the decentralised installation of a large number of electrolysers. Furthermore, the energy costs are higher if the electricity used for producing the hydrogen is purchased from the grid.<sup>116</sup> With regard to decentralised production, widely distributed micro-solutions at the wind power or photovoltaic plants themselves are conceivable if the green electricity is converted directly and without being fed into the grid (compare the "Hydrogen for Trains" scenario → Chapter 4.3).

115 [https://www.plattform-zukunft-mobilitaet.de/wp-content/uploads/2020/10/201012\\_NPM\\_AG5\\_V2G\\_final.pdf](https://www.plattform-zukunft-mobilitaet.de/wp-content/uploads/2020/10/201012_NPM_AG5_V2G_final.pdf) (accessed on 3.11.2020)

116 Presentation given by Dr Werner Ponikwar, Managing Director Linde Hydrogen FuelTech at the Hydrology Online Conference (accessed on 8.10.2020)

H<sub>2</sub> MOBILITY GmbH & Co. KG has provided the hydrogen infrastructure in Germany since 2015. Its shareholders are the car manufacturer Daimler AG, the gas manufacturers Air Liquide and Linde, and the petrol station operators OMV, Shell and TOTAL. In September 2020, 85 public filling stations were listed in Germany, with further stations existing on company premises.<sup>117</sup> This means that the original target of 100 hydrogen filling stations by 2020 has been missed.<sup>118</sup> In Germany, the filling stations are only to be expanded where there is a regional need<sup>119</sup>. In contrast, Bavaria's hydrogen strategy explicitly envisages the construction of 100 additional filling stations by 2023. Whether this can succeed, with a subsidy rate of 90% for public and up to 60% for corporate filling stations, is uncertain given the subsidy volume of €50 million and investment costs of €1 million per filling station.<sup>120, 121</sup>

The total cost of converting the infrastructure to hydrogen is estimated at €61 billion<sup>122</sup>. The costs for the charging infrastructure of battery-powered vehicles were also compared in the estimation. Both technologies are necessary if the transport transition is to succeed, i.e. charging infrastructure for electric vehicles and refuelling infrastructure for hydrogen vehicles. At the time of the 2017 study, it was deemed that the charging station network would be more cost-intensive in the long term than the required network of hydrogen filling stations<sup>123</sup>. Whether this still applies in 2030 is highly uncertain due to the positive economies of scale of electromobility. Rather, to ensure maximum efficiency and effectiveness it is crucial that both technologies are used depending on the suitability of each for specific applications. This can be further supported by demand-oriented and cost-optimised expansion of the respective infrastructure based on the following precept: as little investment as possible, but as much as is necessary.

117 <https://h2.live/> (accessed on 14.11.2020)

118 <https://www.bundestag.de/resource/blob/660806/cdabebcac5d4d8f74ade53fba9bf95b8/WD-8-070-19-pdf-data.pdf> (accessed on 14.11.2020)

119 [https://content.h2.live/app/uploads/2019/07/H2M\\_Broschuere\\_Deutsch\\_201906.pdf](https://content.h2.live/app/uploads/2019/07/H2M_Broschuere_Deutsch_201906.pdf) (accessed on 14.11.2020)

120 <https://www.stmwi.bayern.de/wasserstoffstrategie/> (accessed on 14.11.2020)

121 <https://www.auto-motor-und-sport.de/tech-zukunft/alternative-antriebe/130-wasserstoff-tankstellen-ausbau/> (accessed on 14.11.2020)

122 <https://www.fz-juelich.de/SharedDocs/Pressemitteilungen/UK/DE/2017/2017-03-09-h2-szenario-ires.html;nn=721054> (accessed on 14.11.2020)

123 <https://user.fz-juelich.de/record/842477> (accessed on 14.11.2020)

# 6. Transport – Vehicle types and operational forms

The functional scope of vehicle assistance systems will continue to increase by 2030. This and an increasing number of safety requirements will make different levels of automated driving possible both on closed routes and public roads. However, the technical framework and legal guide lines still need to be established before fully autonomous driving is possible.

In 2030, there will still be cars, trucks and buses which are driven by people but they will be equipped with elaborate driver assistance systems and many additional functions. Highly automated level 4 driving (→ Figure 20) will also be a matter of course by 2030.

For passenger transport, (partial) automation of the driving operation is promising, as it allows the driver to rest or perform other tasks. Mobile care workers, for instance, could complete their paperwork during the driving time, thus freeing up productive time for work with the patient, or even allowing more patients to be seen during the working day.

In cases where the logistics service includes freight transport, in 2030 it will be technically possible to cover

the entire route, including the remaining “last mile” as it is known in the logistics industry, fully autonomously. On the other hand, for the time being there is no desire to complete this last mile without the flexible skills of a human operator if a personal handover is desired and linked premium services can be offered.

In the long term, increasing e-commerce and the resulting growth in parcel volumes as well as demographic change are expected to foster the development of an automated to fully autonomous logistics industry. Depending on technological developments and the associated use scenarios, established vehicle manufacturers and service providers are already being called upon to rethink their offerings. An interesting application could be “autonomous vehicle fleets” which take care

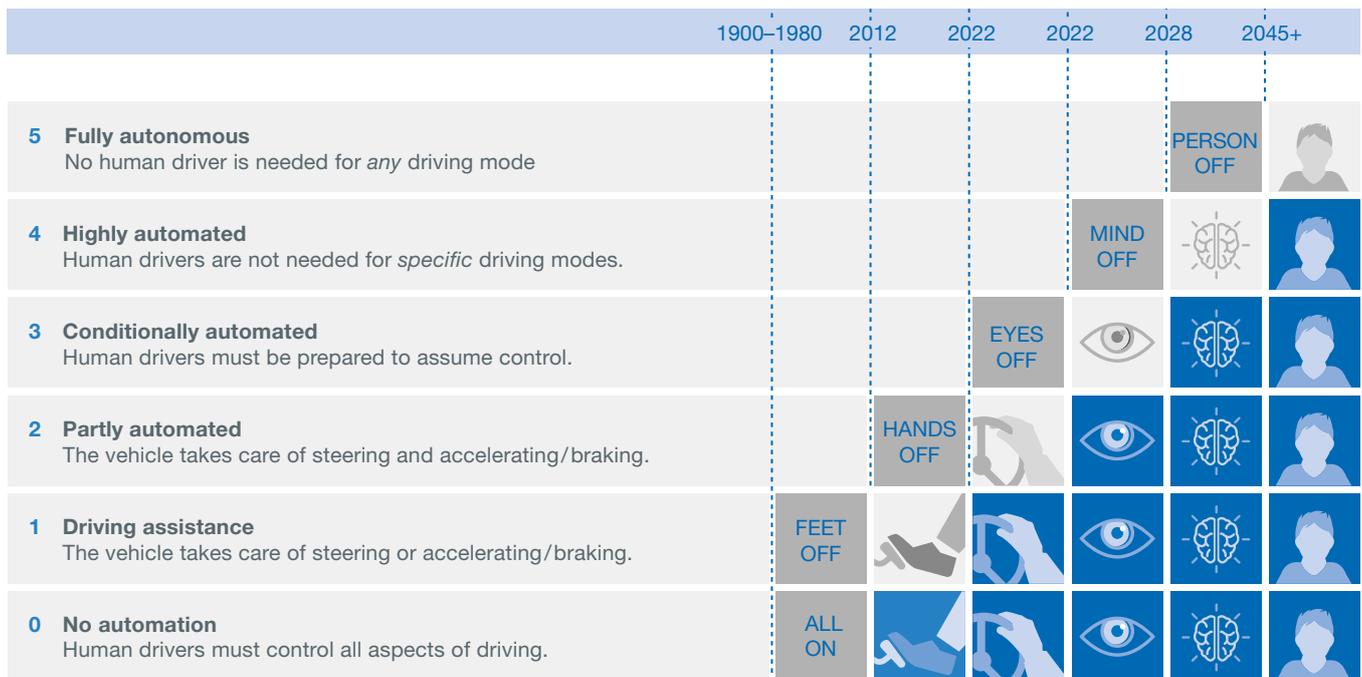


Figure 20: Phased approach for autonomous driving

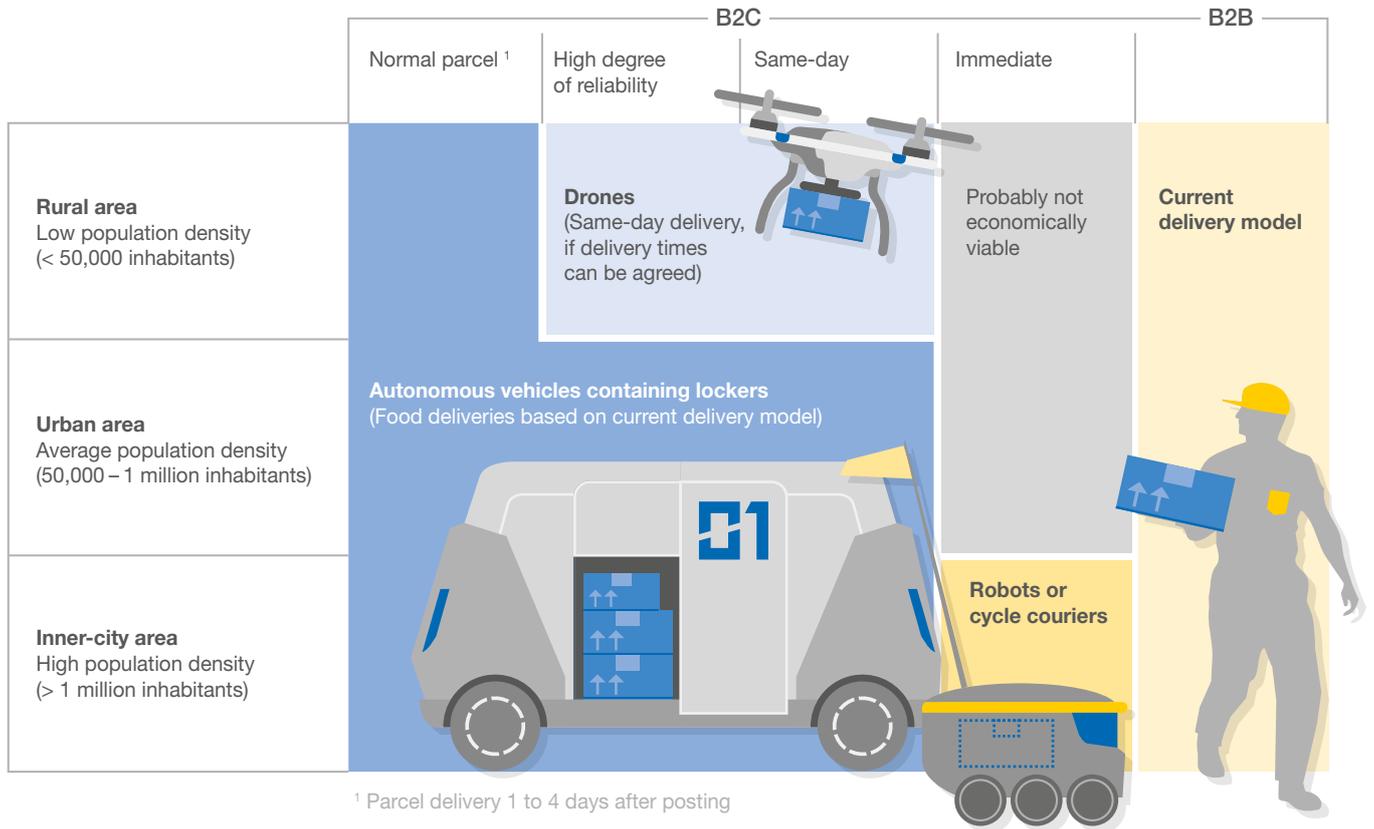


Figure 21: Future delivery options (based on McKinsey information)<sup>124</sup>

of local public transport or urban goods deliveries, for example. In the future, different delivery options will be available depending on the requirements of the recipients and their geographical location (→ Figure 21<sup>125</sup>).

The variety of possible use and application scenarios for autonomous vehicles is of particular interest in electromobility, as the topic of ICT is of special relevance here. The mass deployment of fully autonomous vehicles, both on land and in the air, is currently prevented by legislation. A further amendment to the Road Traffic Act, which was amended in March 2017, is necessary for fully autonomous driving.<sup>126</sup>

The Federal Ministry of Transport and Digital Infrastructure prepared a draft on the regular operation of autonomous vehicles for publication in the second half of 2020. The draft was submitted to the relevant departments for approval in December 2020. This does not advocate completely unmanned, fully autonomous driving, rather an operator-based approach in which the vehicles are monitored, i.e. there is technical oversight and intervention in case of an emergency. If the amendment is applied in its proposed form, this will make Germany the first country in the world with legislation for completely driverless vehicles. If German companies succeed in meeting these requirements technically and economically, this will give them the opportunity to become pioneering innovation leaders in the global market.<sup>127, 128, 129, 130</sup>

124 <https://www.rolandberger.com/de/Publications/FreightTech-Die-Zukunft-der-Logistik.html> (accessed on 23.10.2020)

125 [www.mckinsey.com/~/media/mckinsey/industries/travel\\_transport\\_and\\_logistics/our\\_insights/how\\_customer\\_demands\\_are\\_reshaping\\_last\\_mile\\_delivery/parcel\\_delivery\\_the\\_future\\_of\\_last\\_mile.ashx](http://www.mckinsey.com/~/media/mckinsey/industries/travel_transport_and_logistics/our_insights/how_customer_demands_are_reshaping_last_mile_delivery/parcel_delivery_the_future_of_last_mile.ashx) (accessed on 3.5.2018)

126 [www.bundesregierung.de/Content/DE/Artikel/2017/01/2017-01-25-automatisiertes-fahren.html](http://www.bundesregierung.de/Content/DE/Artikel/2017/01/2017-01-25-automatisiertes-fahren.html) (accessed on 3.5.2018)

127 <https://www.handelsblatt.com/unternehmen/industrie/gesetzesvorhaben-betriebserlaubnis-fuer-autonomes-fahren-soll-81-992-euro-kosten/26172020.html?ticket=ST-4876910-pikZ02idjuS7eHfzWXaq-ap5> (accessed on 1.12.2020)

128 <https://www.heise.de/news/Gesetzesentwurf-Scheuer-will-Regelbetrieb-autonomer-Fahrzeuge-einleiten-4920962.html> (accessed on 1.12.2020)

129 <https://background.tagesspiegel.de/mobilitaet/gesetz-zum-autonomen-fahren-bettvorleger-oder-sprungbrett-fuer-den-oePNV-der-zukunft> (accessed on 1.12.2020)

130 <https://www.all-electronics.de/erster-gesetzesentwurf-zum-autonomen-fahren-vorgestellt/> (accessed on 1.12.2020)

New providers are entering the market and are already putting innovative solutions in place, such as shared logistics (e.g. the Timocom freight and vehicle space exchange). Here, companies either share storage or goods handling infrastructure, for example, or make optimised use of their transport capacities by bundling their transportation. Crowd logistics applications are also conceivable for delivery (→ Chapter 9.5). Here, transport is shifted from classic logistics service providers to private individuals with spare capacity. Crowd logistics handles point-to-point deliveries in mostly urban areas, i.e. the direct transport of goods from the point of dispatch to the destination.

For logistics and mobility in densely populated urban areas and within a radius of about 150 km, it will be possible to use purely battery-electric vehicles that are comparable in size to today's Sprinter models. Ideally, small, fully autonomous vehicles with speed limits and restricted movement radii will already be in use by 2030, supporting the upcoming technological leap towards fully autonomous vehicles.

For passenger transport, there could be increasing use of partial to highly automated and fully autonomous people movers or minibuses by 2030. Here, feeder or distribution transport solutions in the form of intelligent networking with existing transport services look especially promising. Autonomous vehicles must be adapted technically to mesh with the existing traffic flows. Especially with regard to the speed and reliability of the vehicles, major technical hurdles will have to be overcome and regulatory approval will subsequently be required from the legislator. Whether or not there is sufficient time before 2030 cannot be predicted due to the unforeseeable speed of development of the underlying technology.

Although Tesla is already advertising autopilots and also autonomous driving for its vehicles in 2020, these are actually more like driving assistance systems<sup>131</sup>. Herbert Diess, Volkswagen Group CEO, expects the first fully autonomous vehicles to be ready for the market between 2025 and 2030, although they will not necessarily be VWs<sup>132</sup>.

Fully autonomous – i.e. level 5 – driving will probably only become reality in the long term, by 2045 or so (in Germany). Technical assistance systems for drivers, however, are already available today and the range of applications for these systems will continue to expand.

With regard to autonomous delivery solutions, the Postal Services Act would also have to be amended, depending on the specific nature of the handover. This would simplify the use of autonomous delivery systems in Germany because it would relieve the strain on freight or logistics service providers, and impersonal delivery in the form of (lockable) drop-off points would become the standard.

In addition to this wide range of battery-powered vehicles, fuel cell vehicles will also be in use in 2030 (→ Figure 14). They have a better cost-benefit ratio over long-distances and represent a more or less one-to-one replacement of diesel trucks. This is because any attempt to achieve complete electrification of long-distance transport without the use of fuel cell vehicles would require about 1/3 more vehicles to provide the same transport capacity<sup>133</sup>. Electric and hydrogen buses are currently competing in the public transport market. Berlin aims to convert its bus fleet to battery-electric drives by 2030 and is investing €2 billion in this and in the necessary infrastructure via the new BVG transport contract<sup>134</sup>. North Rhine-Westphalia's Hydrogen Roadmap, by contrast, aims to deploy 3,800 fuel cell buses for regional public transport by 2030<sup>135</sup>. There is therefore no clear trend in favour of one technology or the other in public transport at present or in the years leading up to 2030.

131 [https://www.tesla.com/de\\_DE/autopilot](https://www.tesla.com/de_DE/autopilot) (accessed on 11.12.2020)

132 <https://www.wiwo.de/my/unternehmen/auto/herbert-diess-herr-osterloh-weiss-was-er-an-mir-hat/26681784.html> (accessed on 11.12.2020)

133 Frank Dreeke, Chairman of the Executive Board, BLG LOGISTICS GROUP AG & Co. KG, presentation given at the German Logistics Congress 2020, 21.10.2020

134 <https://www.berlin.de/rbmskz/aktuelles/pressemitteilungen/2020/pressemitteilung.957313.php> (accessed on 14.11.2020)

135 <https://www.land.nrw.de/pressemitteilung/wasserstoff-roadmap-fuer-nordrhein-westfalen-vorgestellt> (accessed on 14.11.2020)

# 7. Modes of transport

Transport services are provided on water, rail, road and in the air. These four modes of transport present different possibilities for electrification. Railways, for example, are technically easier to electrify than motorways. It is almost impossible to electrify waterways, at least using a power line. Here, electrification would have to be effected in the vessels themselves in the form of batteries or through the use of hydrogen, similar to aircraft. The current state-of-the-art still requires liquid fuels for aviation and shipping (→ Figure 22). The focus of the ICT for Electromobility Technology Programme is on urban delivery traffic and the commercial vehicles required for it, which offer great potential for electrification. Couplings with other modes of transport (modal split) are also considered in the programme.

## 7.1 Increase in transport capacity

By 2030, all modes of transport will have experienced growth. Both the transport volume (in tonnes) and the transport distances (in kilometres) will increase. In rail and road transport, the percentage increase in transport capacity (tkm) will be greater than that of the transport volume (t), which is attributable to the longer distances. Overall, however, water and rail modes of transport will see greater volume growth than road transport.<sup>136</sup>

## 7.2 Use of existing networks

The availability of the underlying network, i.e. the density and quality of its expansion, is decisive for the provision of services.

In terms of urban mobility and logistics, the road is the primary mode of transport and the dense urban and suburban road network is the most important distribution network. The roadways are already heavily used and can hardly be made greater use of with the current

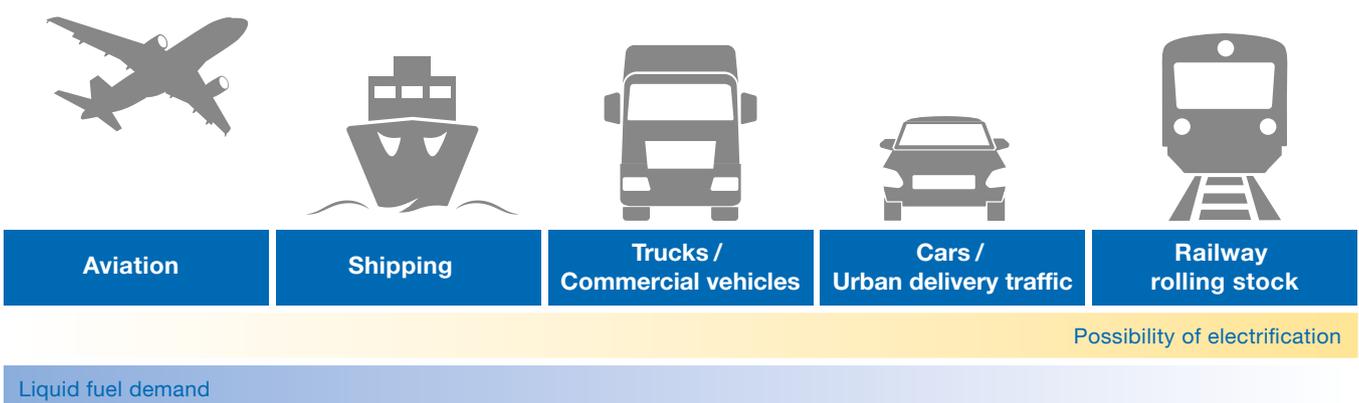


Figure 22: Transport modes and drive energy

<sup>136</sup> [https://www.bmvi.de/SharedDocs/DE/Anlage/G/verkehrsverflechtungsprognose-2030-zusammenfassung-los-3.pdf?\\_\\_blob=publicationFile](https://www.bmvi.de/SharedDocs/DE/Anlage/G/verkehrsverflechtungsprognose-2030-zusammenfassung-los-3.pdf?__blob=publicationFile) (accessed on 30.10.2020)

technical possibilities. In many cases they are at their capacity limits. Autonomous vehicles with platooning capability, i.e. individual vehicles that are closely grouped together, allow significantly more vehicles on the existing road network.

The railway mode is scarcely used as a mode in urban logistics transport. The end of 2020 will see the discontinuation of the former VW Cargotram showcase project in Dresden for making deliveries to and from Volkswagen's Transparent Factory in a central location within the city<sup>137</sup>. Regardless of this setback, combined road/rail transportation solutions are certainly viable options for urban supply chains. The urban networks are not usually very busy in the off-peak hours, meaning that additional rail services could be provided here. Alternatively, rail vehicles or buses offer the possibility of piggybacking, i.e. allowing drones to land on them and travel along a section of track in order to save energy. The operating radius of the drones and the delivery catchment area could be increased by piggybacking because the drones would then not have to use their own drive energy on certain journeys. However, such extended use of "free-riding" is not realistic at present, as contemporary vehicles carry a great deal of technical equipment in the roof (e.g. ventilation and air-conditioning systems, pantographs, accumulators) and have little or no free space.

There are only a few inner-city waterways in Germany. And water transport unit sizes are usually very large. In Germany, there are therefore few opportunities to use the waterways for urban logistics. Nevertheless, solutions for the collection of multiple small and medium-volume goods could also be introduced here, assuming that the necessary transshipment points exist within the city or can be provided. In Berlin, for instance, it is conceivable that the central areas flanking the Spree or the Landwehr Canal could use water shipment for waste disposal transportation.

In 2030, air transport will probably occupy a niche position in urban areas. Drones are conceivable in certain delivery scenarios (→ Chapter 9.2), and prototypes are already being tested and deployed in isolated, small-scale projects.<sup>138</sup> But what is needed here are intelligent concepts that combine drones with other vehicles to increase the radius of the operational area (regardless of battery size). Furthermore, the relatively strict legislative restrictions remain an obstacle to widespread use. Thus, appropriate simplifications would have to be made here, too. This is not, however, currently foreseeable.

In response to the increasing transport capacity, the aim now is to improve capacity utilisation, irrespective of the mode of transport used. At present there is increasing overcrowding on major road and rail routes, especially around conurbations<sup>139</sup>. Since unlimited expansion is not possible, work must be done to optimise utilisation of the existing networks. Solutions and technologies aimed at enabling denser usage are needed. Otherwise, motorway congestion, standing freight trains and stranded inland vessels will preclude any possibility for increased transport volumes.

137 <https://www.saechische.de/dresden/lokales/dresden-cargotram-ende-einer-aera-5297894-plus.html> (accessed on 26.10.2020)

138 [www.post.ch/de/ueber-uns/unternehmen/innovation/innovationen-der-post-fuer-sie/drohnen](http://www.post.ch/de/ueber-uns/unternehmen/innovation/innovationen-der-post-fuer-sie/drohnen) (accessed on 30.10.2020)

139 [https://www.bmvi.de/SharedDocs/DE/Anlage/G/verkehrsverflechtungsprognose-2030-netzumlegungen.pdf?\\_\\_blob=publicationFile](https://www.bmvi.de/SharedDocs/DE/Anlage/G/verkehrsverflechtungsprognose-2030-netzumlegungen.pdf?__blob=publicationFile) (accessed on 30.10.2020)

# 8. Transport and logistics actors

The transport and logistics actors are consignors and consignees, (freight) forwarders, carriers and CEP service providers. Their equivalents in the passenger transport sector are customers and service providers. In both cases, further providers can be subcontracted to take care of parts of the process.

## 8.1 Logistics actors and their growth potential

Usually, the goods are collected from the manufacturer (or consignor) in batches > 1, although the manufacturing process of certain custom-built products can give rise to other transport volumes (→ Figure 23). Feeder traffic is used to deliver the goods over the first mile to a (collection) depot. This is followed by long-distance transport and further transshipment to another depot and finally delivery over the last mile to the consignee or (end) customer. Regarding the electrification possibilities within this transport chain, particular attention needs to be paid to the first and last miles. Long-distance transport can be electric if a rail-based solution is deployed. Alternatively, hydrogen or e-fuels can be used for long-distance transport.

The **consignor** (1) invites door-to-door delivery bids. In a departure from the previous approach, increasing digitalisation is opening up opportunities for the use of online tenders, price enquiries and contract awarding processes, including transport exchanges (→ Chapter 9.5). The use of price transparency software or intelligent reconciliation systems can also be beneficial for the contractor. As with the consignor, they can help speed up the organisational aspects of the order processes. If the shipment is made in standardised units (e.g. parcels, packages), the consignor can make use of existing services provided by various postal companies.

**First mile** (2) transport can be autonomous, if such vehicles are available. The drivers can, however, also be supported by dynamic routing in conventional vehicles. At the same time, today's intelligent labelling systems already allow communication of the current status and geographical location of the consignment to all parties involved in the transparent transport chain.

Different systems are available for **storage** (3). Depending on the organisational specifics, a range of solutions are conceivable: from the more common methods like just-in-time or just-in-sequence, to chaotic or fully automated storage. Storage can also be optimised through digitalisation, for example by means

of in-house routing of individual pickers in the case of chaotic storage, which can yield time and thus cost optimisations.

Increasing digitalisation in **long-distance transport** is already making it possible to predict arrival times through the deployment of telematics systems (4). Here, too, all relevant parties can be kept informed about the status and location of the consignment. Platooning, self-driving trucks, or at least the increased use of driver assistance systems, can help raise efficiency levels here.

**Interim storage** before delivery to the consignee (5) holds further optimisation potential, similar to general storage, as described above. However, there is further potential which can also be tapped along the entire transport chain; for example, through digital consignment notes, smart contracts, value-added insurance and financial services. For example, it is already possible today to link telematics information to individual policyholders, which in turn yields greater flexibility in insurance premiums.

The **last mile** of the delivery from the depot to the consignee (6) is again determined by a range of factors – from automatic routing, route guidance based on disruptions (e.g. road works, traffic jams, closures) and driver assistance systems up to and including autonomous vehicles and fully autonomous delivery. Here, too, digitalisation opens up further potential for corresponding optimisation.

The **consignees**, possibly the (end) customers (7), can influence the delivery process due to the increasingly widespread use of information and communication technologies. They can influence the choice of transport service provider when placing their order, either by selecting or excluding specific companies or by influencing the shipping service via the cost (flat rate). In addition, the consignee can also influence the delivery during the delivery stage itself by choosing a different location or a different time, for instance.

Direct orders, for example from a local bookshop or the after-hours service of a local pharmacy, usually eliminate the need for storage and, of course,

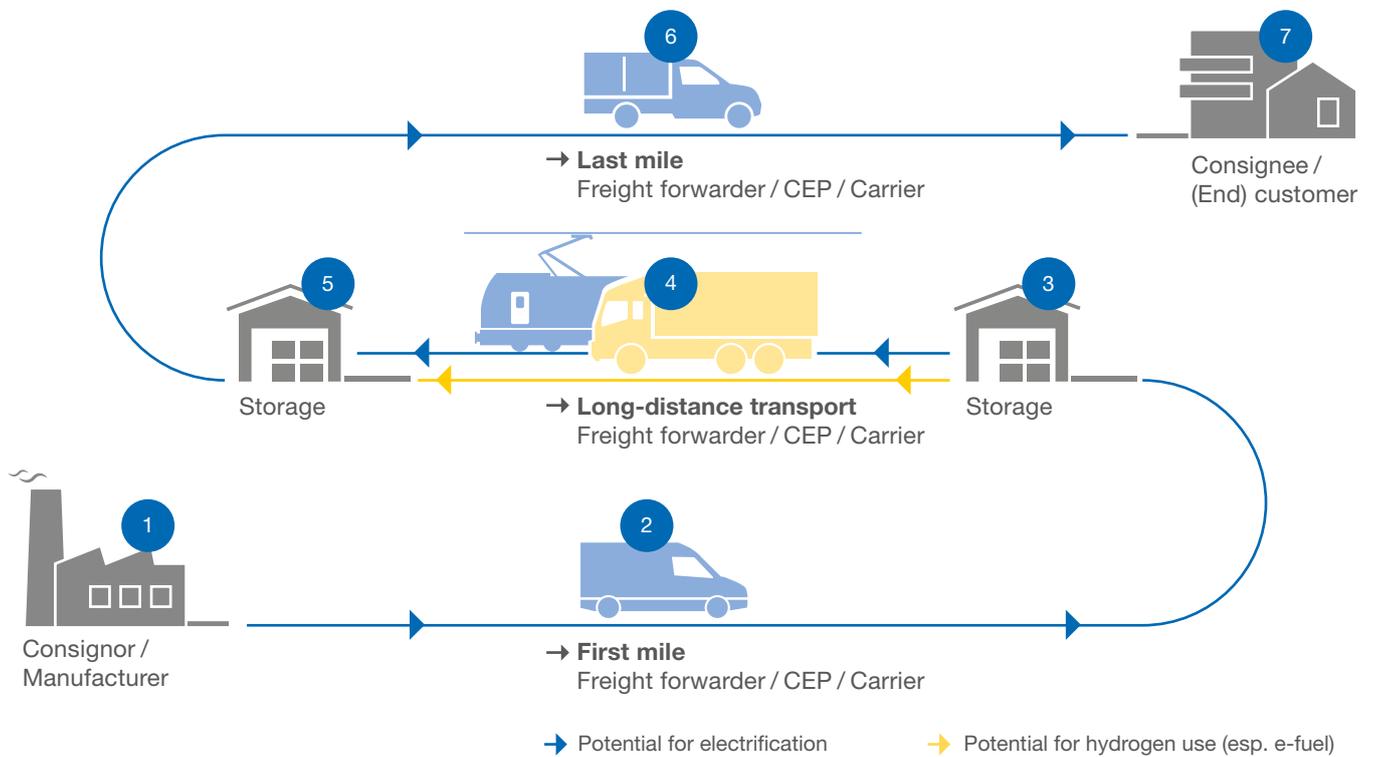


Figure 23: Logistics actors (based on Roland Berger information)<sup>140</sup>

long-distance transport. Here the consignor organises direct door-to-door delivery via a courier service to the consignee. And here, too, there is potential for savings, as already mentioned.

## 8.2 Mobility service providers

Mobility service providers for passenger transport provide their services directly to customers. In urban transport, these have so far been almost exclusively the providers of local public transport. The potential for optimisation stems primarily from the contractual relationship, interaction and processing between service provider and customer. Third parties can also be included in the contractual relationship – taking care of the actual transport service as subcontractors, for instance. One example of this is the BerlKönig platform of BVB (Berliner Verkehrsbetriebe), which can be used to book passenger shuttles. The ridesharing service is operated jointly with the ViaVan start-up.

Digitalisation opens up further opportunities for raising efficiency levels. Real time passenger information can

thus be provided on current departure and transfer times, for example. It would also be possible to pre-book connections if planned changes are no longer possible as the result of delays. This approach would offer advantages to service providers and customers, especially in peripheral areas of urban agglomerations with only infrequent connections. In return, the travel or transport services could be flexibly adapted, which can be particularly helpful in the case of major events and the resulting highly localised additional demand for mobility. Furthermore, a combination of comparatively rigid scheduled services and more flexible shuttle services is also conceivable.

Overall, digitalisation enables even better coordination of supply and demand in (local) public transport. In view of the expected increase in population, especially in the German metropolitan regions, from approx. 16% at present to 19% of the total population by 2030, innovative solutions must be found to cope with the further increase in transport demand<sup>141</sup>.

140 <https://www.rolandberger.com/de/Publications/FreightTech-Die-Zukunft-der-Logistik.html> (accessed on 23.10.2020)

141 <https://www.iwd.de/artikel/zurueck-in-die-stadt-139538/> (accessed on 2.11.2020)

### 8.3 Factors influencing future transport services

Transport services in the future will be determined by three factors: intelligent systems, automation, and integration of these two factors.<sup>142</sup>

Smart systems are based upon the use of sensors and connectivity (IoT – Internet of Things) for collecting and sending data. Standards for short-range communication and for long-range networks are necessary for their correct use. The data generated by the sensors (Big Data) can be supplemented by other technologies (e.g. computer vision, image recognition, artificial intelligence (AI) and machine learning). Only with consistent processing and analysis of all data can the prospective large amounts of data be handled in a targeted manner and used meaningfully.

Data is often described as the currency of the 21st century; the complexity and inherent interconnectedness of logistics offer numerous opportunities for data-driven decision-making and optimisation<sup>143</sup>. The more data is available, the greater the validity of the decisions – assuming that the flood of data is properly managed.

Automation can be based on the intelligent systems using static and mobile automation systems. These include self-driving cars and trucks, unmanned aerial vehicles (e.g. drones) and other driverless transport vehicles. Now with longer operational lives, falling prices and increasing productivity, robotic systems are becoming more common in logistics. Initially, however, they will be used primarily in closed systems, such as warehouses, for efficient order picking – where they can function without any constraints such as breaks, working times or labour costs.<sup>144</sup>

Technologies such as cloud computing, digital ecosystems, logistics platforms, digital twins and blockchain are incorporated to integrate the intelligent systems. The platform solutions of logistics and mobility providers must be able to integrate a variety of stakeholders from different industries and with different degrees of digitalisation.<sup>145</sup> And so digital ecosystems in particular must be easy to understand and intuitive for the individual actors, thus raising confidence in them and encouraging their use.

The three factors (intelligent systems, automation and integration) can jointly increase the transparency and efficiency of future transport services. The market players, be they traditional providers or innovative start-ups, will continue to develop in the future, assuming they make consistent use of information and communication technologies. In the future, we can expect to see large logistics and mobility platforms that offer customers a barrier-free one-stop shop experience. The marketplaces range from simple extra services through to comprehensive “Logistics-as-a-Service” solutions which require consistent and continuous automatic coordination and optimisation between the different parties. In addition, network specialists who can offer diverse and closely interwoven transport services will thrive. The providers will be specialised in individual sectors or regions. This high degree of specialisation makes it difficult to transfer to higher-level, more general digital platforms, but at the same time it represents a very clear unique selling proposition that can be monetised. A third form of provider in the future ecosystem of logistics and mobility is asset operators – i.e. digitalised and efficient infrastructure operators with sophisticated analytical, automation and integration capabilities. They provide their infrastructure on a continuous basis and in optimised form and thus ensure the smooth transport of goods and people. Finally, meta-platforms represent a conceivable fourth, fully integrated form that aggregates information from different sources. In order to counteract the resulting market dominance, there would have to be several of these meta-platforms in the future in order to ensure at least a balancing oligopoly within the market. Alternatively, a parallel series of regulated platforms could emerge.<sup>146, 147</sup>

Here, all providers will strive for direct contact with the customer, as it allows them to win over the customer directly and thus generate business, higher margins and corresponding profits.

142 <https://www.rolandberger.com/de/Publications/FreightTech-Die-Zukunft-der-Logistik.html> (accessed on 2.11.2020)

143 <https://www.rolandberger.com/de/Publications/FreightTech-Die-Zukunft-der-Logistik.html> (accessed on 2.11.2020)

144 <https://www.rolandberger.com/de/Publications/FreightTech-Die-Zukunft-der-Logistik.html> (accessed on 2.11.2020)

145 <https://www.rolandberger.com/de/Publications/FreightTech-Die-Zukunft-der-Logistik.html> (accessed on 2.11.2020)

146 <https://www.rolandberger.com/de/Publications/FreightTech-Die-Zukunft-der-Logistik.html> (accessed on 2.11.2020)

147 Ulrich Müller-Steinfahrt, Head of the Institute for Applied Logistics (IAL), University of Applied Sciences Würzburg-Schweinfurt, talk given at the German Logistics Congress 2020, 23.10.2020

# 9. 2030 logistics scenarios

The development of future logistics services depends on the influencing variables mentioned above, including drive energy, the energy market and charging technologies. There are also other social and retail-specific trends that will influence mobility and logistics in the future. The interplay and mutual interactions among these give rise to descriptive scenarios that illuminate various sub-aspects of logistics in 2030. Finally, certain indications are emerging for sustainable mobility and logistics in the future.

## 9.1 Logistics trends

There are four main urban logistics trends:

1. **Urbanisation** – By 2030, approx. 79% of all residents in Germany will live in cities. This corresponds to an increase of 1.6 million people in the urban population compared to 2018. This is equivalent to the population of the city of Munich – but distributed across all cities.
2. **e-commerce** – Online trade is steadily increasing. The CEP industry is predicting steady growth in the number of consignments, with a 3.8% increase in 2019 compared to the previous year. Every day, more than 12 million items are delivered to around 7 million consignees in Germany; almost 30% of these are commercial customers.<sup>148</sup>
3. **Customer satisfaction** – Customers increasingly compare providers and their suppliers. At present there is a pronounced “right now” mentality. Customers expect same-day or 24-hour delivery if possible, but with no corresponding willingness to pay – especially for alternative delivery options and innovative delivery services.<sup>149</sup>
4. **Retail battle** – High street retailers are not relinquishing the market to the online retailers without a fight. Local deliveries, even of small and very small quantities down to 1 piece, especially in flexible time windows, lead to increased traffic, both through deliveries to town-centre retailers and also to the end customers.

Various possible scenarios can be derived for the logistics sector from this information, each of which addressing and reflecting different aspects. The individual, differentiated scenarios outlined below cover various

facets of transport, distribution, delivery and, in some cases, the associated logistics and mobility energy footprints.

## 9.2 Flybot – the flying robot for autonomous parcel deliveries: an autonomous delivery scenario of the future

Flybots are autonomous aircraft for individual deliveries in urban conurbations. Flybots typically enable delivery to specific consignees at particular locations, pre-arranged at short notice and independent of the actual place of residence or work (→ Figure 24). When agreeing a delivery, consignees initially only indicate their place of residence. Once the consignment has arrived at the distribution centre, the consignees then specify when and where they would like to receive the shipment. This means that deliveries are also possible in public spaces, e.g. in a park, during a walk or at a transfer point. Such highly flexible delivery avoids the logistics service provider, its partners or even neighbours having to store undeliverable consignments.

This drastically reduces the number of uneconomical second and third delivery attempts, or collections from (in some cases) remote pick-up points, as the consignee can be reached at an appropriate time on an appropriate day, as his or her situation allows. Flybots, the “robot flies”, can also be used for picking up returns, for example.

Unlike today's drones, flybots are not limited to specific take-off and landing sites, but search for one themselves. As mechatronic flies, flybots can take off and land anywhere. Flybots bridge the time to collection by hovering like a fly, i.e. vertically overhead, on fixtures such as lampposts or traffic lights. This makes optimum use of public space and reduces the amount of

148 <https://www.biek.de/download.html?getfile=2623> (accessed on 28.9.2020)

149 <https://www.biek.de/download.html?getfile=2623>(accessed on 28.9.2020)



Figure 24: Flybot visualisation

required storage and loading areas. The changes between landing, waiting and taking off are effected using autonomous horizontal and vertical travel and climbing movements and automatic alternation between these. The climbing mechanism of the flybots' autonomous delivery version is based on the Rise robot from Boston Dynamics, and is supplemented by a drone unit for flight. Authentication is conducted via NFC, facial recognition or personal electronic signature (card). This ensures that deliveries are only made to the consignee, which also enables the shipment of sensitive freight (e.g. medicines).

### 9.3 Advertising pillar ("Litfaß") logistics – vendor-independent locker system as urban delivery scenario

The advertising pillar logistics scenario takes the existing infrastructure and puts it to a second use. "Advertising pillar logistics" is a vendor-independent variant of the micro-depot.

The location points here are the advertising pillars found in German towns and cities. Originally built for advertising purposes, there are currently around 51,000 such pillars in residential areas and busy neighbourhoods throughout Germany, most of them used for advertising. However, advertising pillars can also be found in other countries such as Denmark, France, Switzerland, Canada and the USA. In some cases, they already have multiple uses. Ticket machines have



Figure 25: Advertising pillar logistics visualisation

been installed in some pillars in Stuttgart, for example, in Karlsruhe public toilets have been incorporated as street furniture, and in Dresden telephone booths have been installed in some pillars. However, the vast majority are merely empty, enclosed spaces, but with a remarkable reach in terms of attention-grabbing. In Essen, for example, 126 of the 217 of the pillars are located in residential areas and 75 in fashionable districts (with overlaps).

How could these empty spaces and this high availability be put to good use? As urban vendor-independent parcel stations! End customers collect parcels from these round “parcel stations” close to their home or work (→ Figure 25). For this, the advertising pillars are equipped with a mechanical handling system, similar to the automatic systems used in parking towers. Between 75 and 110 parcels (of shoe-box size) can then be stored per location, depending on the size

of the advertising pillar. The parcel pillars are filled by the logistics service providers themselves in a similar way to established systems such as “Packstations”. The service providers benefit because fewer stops are needed to deliver a full day’s tour of parcels (approx. 200 units). This can save personnel costs and vehicle demand, as it does away with the need for highly time-consuming doorstep deliveries. Second delivery attempts, drop-offs at a parcel shop or storing in a branded Packstation are also eliminated (at least for small to medium-sized parcels). In addition, the advertising pillar stations could also accept returns, which the logistics service providers then transport back to the depot. Avoiding empty runs would therefore be a further advantage for the service providers. The collectors can be authenticated, for example, through the scanning of a QR code issued in advance. This means that, unlike in parcel shops, no staff are required, and deliveries can be collected around the clock.

The pillars can still be used as advertising space, thereby maintaining the original benefit and income for the outdoor advertisers. Initial investment is required to install the necessary technology. Here, a cooperation network between various logistics service providers and outdoor advertisers could provide a stable partnership basis.

The pillars are basically independent locker systems that can be used by all logistics service providers (unlike DHL parcel stations or Amazon Lockers, for example).

When the Berlin pillars changed their operator from Wall AG to a Stuttgart-based service provider at the end of 2019, the approximately 2,500 existing pillars were dismantled in order to replace them with 1,500 more up-to-date models<sup>150</sup>. Currently, about 1,000 advertising pillar locations are uneconomical for Ilg-Außenwerbung GmbH because they are designed "purely" for advertising.<sup>151</sup> This therefore represents a unique opportunity for Ilg-Außenwerbung as a new operator. The concept of the advertising pillar is adapting to the shifting requirements of a changing society, while generating added economic value for the operator. A service life of 60–70 years can be expected, even though Ilg-Außenwerbung itself will initially only operate the pillars for 15 years. Given the continuous increase expected in delivery items and the associated need for storage space, it would appear to make little sense not to use the limited urban space, either in Berlin or in other cities.

#### 9.4 PC – Parcel Concierge – Bundling of parcels and customised delivery

The increasing volume of parcels is leading to more logistics-related traffic in city centres. Customers order from different (online) retailers who either use their own courier services, such as Amazon, or other providers (e.g. UPS, DHL, DPD, Hermes). Especially in densely populated urban areas, the individual service providers do not necessarily share the same routes, meaning that many stops are served multiple times, either on the same day or within relatively short intervals in a week. This can lead on the one hand to frustration on the part of the orderers/consignees if they are not at home and a new delivery has to be made, or the delivery has to be collected from a parcel shop (or neighbour, convenience store, post office station).

The parcel concierge consolidates this distribution traffic to the end customer. The logistics service providers deliver the orders to the concierge service. This is located outside the conurbation in a place with good, rapid-access rail/road connections. Ideally, it is located in the immediate vicinity of the logistics companies' distribution centres. The parcel concierge collects all time-critical items within an area, sorts and delivers them once a week, for example, within an individually agreed time window (→ Figure 26). Time-critical items are marked separately by the consignor and taken directly to the consignee as express deliveries. The parcel concierge thus does more than simply consolidate the area between two service providers; in case studies, however, this has so far not yielded any positive traffic or logistical benefits.<sup>152</sup> The parcel concierge can minimise urban delivery traffic because consignments which are non-perishable or not otherwise urgent are delivered to the customer in weekly bundles, for example.

The ILoNa – Innovative Logistics for Sustainable Lifestyles project, funded by the Federal Ministry of Education and Research, also concerned itself with the issue of bundled delivery. When asked how much delay they would accept if their deliveries were bundled, only 10% of respondents declared that they would find any delay or a delay of only one day unacceptable. The vast majority of respondents would also have no problem with longer delays.<sup>153</sup>

The parcel concierge reduces or eliminates the mileage involved in making individual deliveries and the carbon footprint of the total delivery is lower than the sum of the CO<sub>2</sub> emissions for individual deliveries. The parcel concierge minimises not only the CO<sub>2</sub> footprint, but also the costs for individual deliveries. Fewer stops are necessary on each current standard route, because direct but unsuccessful delivery attempts are eliminated, and the rising overall volume of consignments can be handled with the same or fewer staff numbers. On the other hand, customers will have to pay a surcharge on the usual shipping costs for "instant" delivery. The corresponding expenses for the logistics companies will lead directly to higher revenues and the end consumer (in the long term) will undergo a change in mentality away from "right now" to "later/bundled" delivery.

If necessary, the parcel concierge can take care of extra services such as returns and reversals. This would

150 <https://www.tagesspiegel.de/berlin/werbeflaechen-in-berlin-2500-berliner-litfasssaehlen-werden-abgebaut/23924682.html> (accessed on 5.10.2020)

151 <https://www.tagesspiegel.de/berlin/werbeflaechen-in-berlin-2500-berliner-litfasssaehlen-werden-abgebaut/23924682.html> (accessed on 5.10.2020)

152 <https://www.biek.de/download.html?getfile=2326> (accessed on 8.10.2020)

153 Report on Key Points of Sustainable Lifestyles for Innovative Logistics, Results of ILoNa Work Package 2.2, 2016



Figure 26: Parcel concierge visualisation

offer a further benefit to end consumers. In addition, the parcel concierge can use any freed-up parcel volumes to make other deliveries or for collecting future deliveries. This would also make it possible to expand the business model.

### 9.5 Last Mile Market – the exchange for unused delivery volume in urban areas

Unused delivery volume in courier and parcel vehicles, as often occurs during the course of the day and is especially prevalent during return trips to the distribution centre, is uneconomical in terms of energy consumption. Even if the vehicles are CO<sub>2</sub>-neutral thanks to the use of renewable electricity and battery-electric drives, this still represents an uneconomical use of resources that should be avoided in the interests of long-term

and comprehensive sustainability. The same applies to transport in privately-owned vehicles. Here, too, a great deal of empty space is moved along regular routes.

This is where the Last Mile Market comes in: an exchange for unused delivery volume in urban areas. Similar platforms to the established Timocom freight exchange for large-volume freight transport within Europe are being set up in conurbations and large cities. The Last Mile Market brings together suppliers and buyers of (in most cases) urban transportation (→ Figure 27). Free capacity is reported to a logistics exchange, as is the corresponding demand.

Prices are formed on the platform based on the market laws of supply and demand, comparable to a stock exchange. Further de-regulation and flexibilisation of the postal and parcel market has led to large commercial providers, one-man businesses and part-time jobbers

offering their spare capacity <sup>154</sup>. All market players report their spare capacity, standard routes, financial and timing conditions to the system. Based on supply and demand, the exchange system automatically negotiates prices via digital agents. Both parties explicitly agree to the automatically negotiated price and conclude a binding “contract of carriage” between them. <sup>155</sup>

The Last Mile Market opens up previously unused transport capacity. This helps avoid unladen runs and reduce the overall amount of pure delivery traffic because it can be combined with other transport services.



Figure 27: Last Mile Market visualisation

154 [https://logistik-heute.de/sites/default/files/public/data-fachartikel/crowd\\_logistik\\_logistik\\_heute\\_summary\\_final\\_v2\\_pdf\\_11563.pdf](https://logistik-heute.de/sites/default/files/public/data-fachartikel/crowd_logistik_logistik_heute_summary_final_v2_pdf_11563.pdf) (accessed on 13.11.2020)

155 Assuming a broadly constant provision of capacity, prices will rise due to scarcity at times of increased demand, and then fall at times of low demand. The assumption of stable provision of capacity is based on the present restrictions of the Postal Act, which sets out the legal framework for the provision of corresponding services.

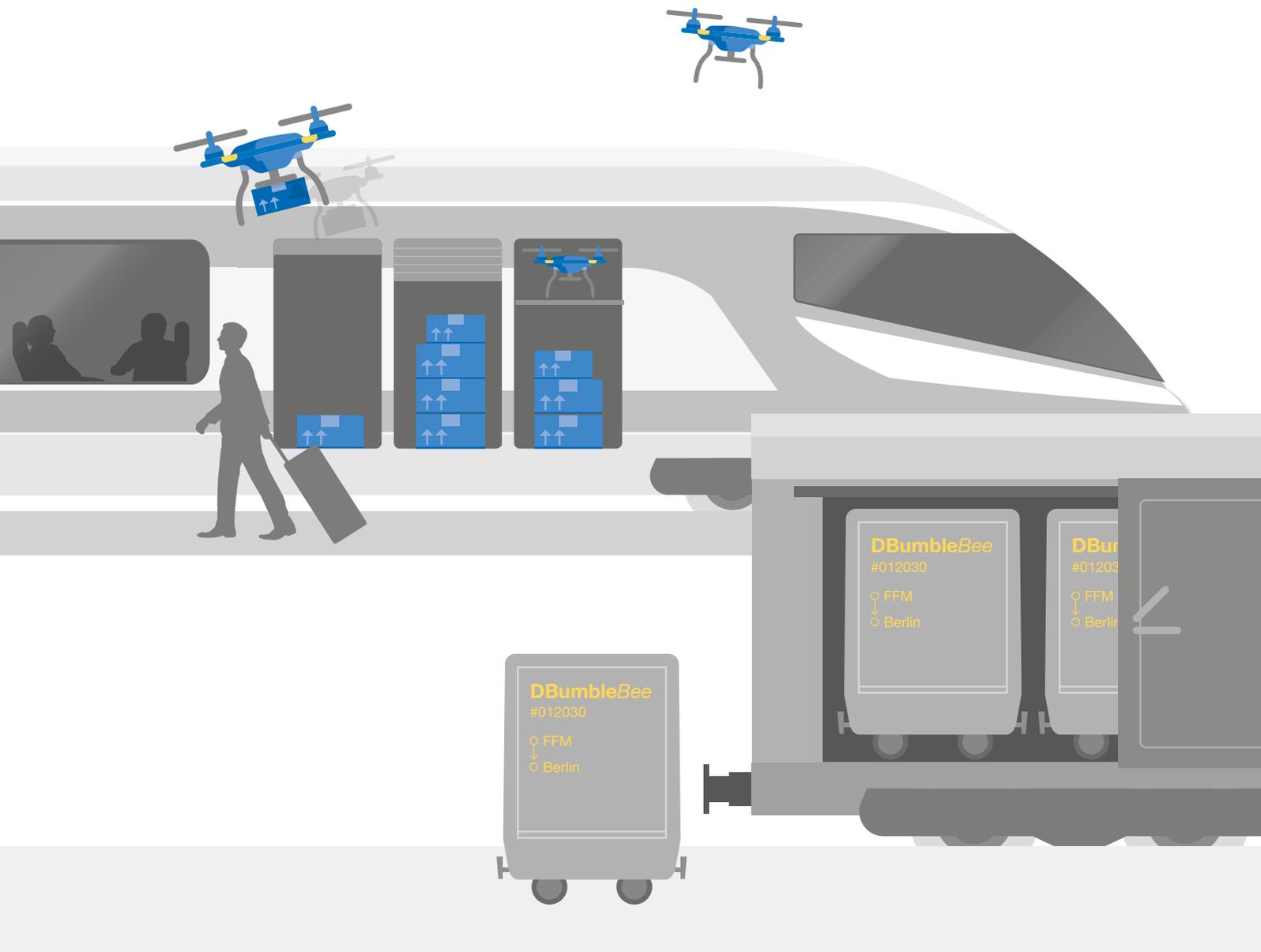


Figure 28: DBee Logistics visualisation

## 9.6 DBee logistics – the multimodal rail logistics of the future

Multimodal logistics will be the flexible backbone of the CEP sectors in 2030. Combining different modes of transport and vehicles will make transport even more efficient and optimise the delivery process. The rail network is used for long distances. One goods train carries the equivalent of 52 truck loads and can replace approx. 1 million truck journeys per week, depending on the deployment scenario<sup>156</sup>. At the end of 2020, DB Cargo announced an overnight delivery service

using its express train network. An additional aim of the service is to connect customers who do not have their own siding to the 140 marshalling yards and hub stations as connection points<sup>157</sup>. From October 2020, DHL's Christmas parcel delivery will also be supported by DB Cargo, with up to 29 trains on weekends<sup>158</sup>.

In order to exploit this potential more fully, passenger trains will in future include special compartment areas and also entire carriages for general cargo. Similar to a beehive, these will fill and empty themselves at the transshipment stations. Drones and small autonomous

156 Sigrid Nikutta, Member of the Management Board of DB Cargo, presentation given at the German Logistics Congress 2020, 21.10.2020

157 <https://www.rnd.de/wirtschaft/expresszug-netzwerk-der-deutschen-bahn-so-will-db-cargo-chefin-neue-kunden-gewinnen-SMZRSZXHPBFY-PO6UJWWC4U5HJI.html> (accessed on 11.12.2020)

158 [https://www.linkedin.com/posts/db-cargo-ag\\_dbcargofaeuhr-logistik-transport-activity-6743204155990515712-kMMX](https://www.linkedin.com/posts/db-cargo-ag_dbcargofaeuhr-logistik-transport-activity-6743204155990515712-kMMX) (accessed on 11.12.2020)

vehicles will be used for this purpose. The retailer fills them, and then they cover the first mile to the train autonomously. They independently seek out their automatically assigned place in the carriage where they are loaded by the on-board network during transportation. Finally, at the destination, they again swarm out autonomously for the last mile to make the final delivery (→ Figure 28). End customers can use this ic:kurier 2.0<sup>159</sup> service to order express items from all German cities, for example, and rely on same-day delivery, thanks not least to the high frequency clock-face scheduling system which operates in Germany. These small, individual delivery units are referred to as DBees in railway jargon.

In addition, the DB Cargo division of Deutsche Bahn will have returned almost all its interurban postal traffic to the railways by 2030. Bahnpost 2.0 will transport all regular non-local mail and parcels overnight within Germany. Pre-sorting will take place in the town of origin, and be conducted automatically in the destination container. These load themselves into the corresponding postal route carriages. These individual carriages can be combined with other orders or trains via the digital coupling, as required. Thanks to the high frequency of

DB Cargo's nightly goods train service, automated container transfer at rail network hubs represents a favourable option for all locations that cannot be reached with direct connections. Early in the morning the containers, called DBumbleBees (on account of the larger units involved) arrive at their destination and make their own way to the local distribution centre. There, the pre-sorted local and non-local consignments are "married" up. This means that only one delivery is necessary per addressee per day. As a result of the climate policy ban on overnight airmail and the greatly increased reliability of the DB Cargo division, Deutsche Post has returned almost completely to its previously very close logistics partner. Not least because delivery by rail is based on a supply chain which runs entirely on green electricity, which is what end customers will demand in 2030.

## 9.7 Starting points for sustainable logistics

As described in the 2030 logistics scenarios (which compete with each other in certain aspects), the overarching goals of sustainable transport logistics are lower energy or resource consumption and lower CO<sub>2</sub> emissions per consignment.

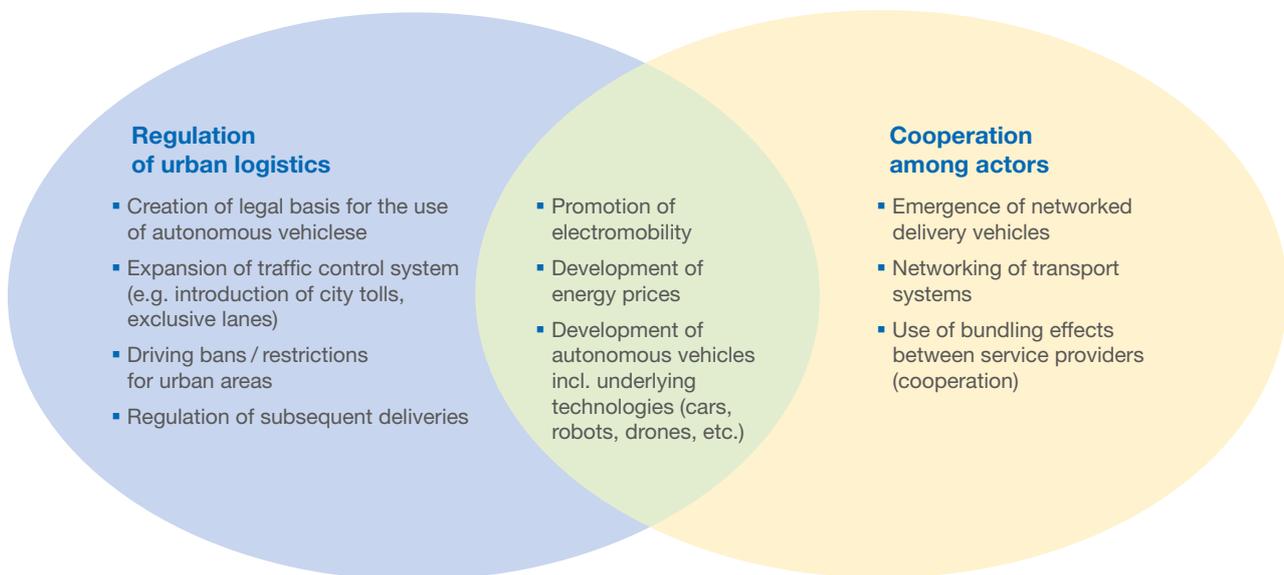


Figure 29: Dimensions for logistics scenarios 2030 (based on information from Roland Berger)<sup>160</sup>

159 [https://www.bahn.de/p/view/angebot/zusatzticket/ic\\_kurier.shtml](https://www.bahn.de/p/view/angebot/zusatzticket/ic_kurier.shtml) (accessed on 2.11.2020)

160 <https://www.rolandberger.com/de/Publications/Wie-wird-urbane-Logistik-2030-aussehen.html> (accessed on 3.11.2020)

Five mutually reinforcing steps can be taken to influence traffic in order to achieve these goals <sup>161, 162</sup>:

1. Increase of transport utilisation through reduction of unladen kilometres
2. Reduction of transport volume, number of journeys
3. Reduction of average transport distances
4. Shift to environmentally friendly modes of transport
5. Environmentally friendly handling of consignments

As a final resort, the remaining burdens can be balanced through a programme of "neutralisation".

The sustainability of logistics and mobility services can be analysed up to and including the carbon footprint of individual runs. In the future, it would also be conceivable to assess the carbon footprint down to each individual consignment or journey. Footprint assessments of the drive energy are a prerequisite for providing such documentation. One solution is the well-to-tank approach, in which the (in some cases) highly complex upstream energy chain is considered up to the point of dispensing at the filling station, particularly in the case of electric and fuel cell vehicles. The well-to-wheel approach examines the entire locomotion impact chain. It analyses the extraction and provision of drive energy up to the conversion into kinetic energy. The most comprehensive, but also the most complex, studies are those covering the entire life cycle of a product (cradle-to-grave). For mobility and logistics, these have to be broken down in turn to individual runs or consignments. This is not a realistic proposition at present, but it would be a multi-faceted challenge for future research projects. Ideally, a simple and readily comprehensible sustainability label or sustainability class (analogous to the energy efficiency class) could also be designed for end consumers and customers.

In order to achieve sustainable CO<sub>2</sub>-neutral mobility and logistics with a view to 2030 and 2050, there must be regulatory intervention on the part of the state, and the market participants should start making their preparations for voluntary cooperation right now (→ Figure 29)<sup>163</sup>. The ICT for Electromobility funding programme can help in the efforts to achieve sustainable mobility and logistics, as it supports concrete cooperation between economic actors and innovative projects.

161 Ulrich Müller-Steinfahrt, Head of the Institute for Applied Logistics (IAL), University of Applied Sciences Würzburg-Schweinfurt, presentation given at the German Logistics Congress 2020, 23.10.2020

162 Christoph Bornschein, CEO of TLGG Group, presentation given at the German Logistics Congress 2020, 21.10.2020

163 <https://www.rolandberger.com/de/Publications/Wie-wird-urbane-Logistik-2030-aussehen.html> (accessed on 3.11.2020)

# 10. Current trends

The aspects already presented are being influenced, at least in part, by the corona pandemic. It is not yet possible to determine whether this influence will continue in the medium and long term. Government measures aimed at promoting CO<sub>2</sub>-neutral transport should be mentioned as a further regulatory factor. These can be direct measures which promote electromobility, or they can act indirectly as restrictive bans on environmentally harmful technologies.

## 10.1 Corona-related implications and challenges

The Apian project of the British National Health Service (NHS) is a start-up that provides a rapid-response drone service between individual clinics to exchange laboratory samples and protective equipment over distances of up to 100 km.<sup>164</sup> It is thus very similar in its application to the flybot scenario (→ Chapter 9.2).

Other assumptions, such as energy consumption, of both overall current and charging current only, will fall short of previous projections, but only for a short period. The International Energy Agency (IEA), for example, is expecting a 5% global decline in absolute energy demand, with fossil energy sources being particularly affected. Renewable energies, on the other hand, could even record slight growth. However, the 18% drop in investment in the energy sector is particularly remarkable.<sup>165</sup>

COVID-19 is affecting the demand for mobility, at least in the short term. During the first lockdown in spring 2020, for example, it collapsed for all modes of transport because there was hardly any need for work- and leisure-related transport<sup>166</sup>. The usual figure of around 40 kilometres per person per day dropped to around 15 kilometres in the last week of March, a decrease of almost two thirds. The remaining journeys were increasingly carried out by bicycle, while public transport use also shrank. The perceived risk of contagion caused a sharp drop in passenger numbers. These were down to between 20 and 30% of the level

recorded in the same period in 2019. There was a slight increase in car use and in the number of journeys made on foot.<sup>167</sup> Assuming that demand normalises in the medium term, increasing use of public transport can be expected again in the future. To achieve this, the federal government, the federal states and the local transport companies, transport associations as well as numerous associations and other partners from the entire mobility industry are supporting the return to the use of buses and trains with a nationwide campaign<sup>168</sup>.

The corona-related lockdown caused an increase in delivery traffic in the first half of the year, especially for everyday goods (groceries, drugstore items, pet supplies). The growth of other major categories such as clothing and entertainment was below average, by contrast, and this overall segment, which was previously deemed “weak”, was able to catch up<sup>169</sup>. Naturally, the Bundesverband E-Commerce und Versandhandel (German E-Commerce and Distance Selling Trade Association) sees no limitations to online retail: “We believe that there are no limits to the types of goods and shopping baskets in e-commerce.”<sup>170</sup> At present it is not possible to foresee the extent to which this significant change in purchasing behaviour will prove lasting or whether, when normality returns, online retail will revert to its more familiar forms and sectors.

The restrictions introduced due to the corona pandemic led to a 7% decrease in CO<sub>2</sub> emissions in 2020. However, annual reductions of 7.6% would be necessary to implement the Paris Climate Agreement.<sup>171</sup>

164 <https://www.gov.uk/government/news/space-company-takes-to-the-skies-alongside-the-nhs> (accessed on 21.10.2020)

165 <https://www.iea.org/reports/world-energy-outlook-2020#executive-summary> (accessed on 2.11.2020)

166 [https://www.destatis.de/DE/Presse/Pressemitteilungen/2020/11/PD20\\_441\\_p001.html](https://www.destatis.de/DE/Presse/Pressemitteilungen/2020/11/PD20_441_p001.html) (accessed on 13.11.2020)

167 [https://www.infas.de/fileadmin/user\\_upload/PDF/Tracking-Report\\_No1\\_infas-Motiontag\\_09042020.pdf](https://www.infas.de/fileadmin/user_upload/PDF/Tracking-Report_No1_infas-Motiontag_09042020.pdf) (accessed on 3.11.2020)

168 <https://www.besserweiter.de/>

169 <https://www.dvz.de/rubriken/logistik/detail/news/bevh-praesident-im-e-commerce-gibt-es-keine-grenzen-fuer-warenarten.html> (accessed on 3.11.2020)

170 Gero Furchheim, BEVH President and Speaker of the Board of Cairo AG, presentation given at the German Logistics Congress 2020, 21.10.2020

171 <https://www.spiegel.de/wissenschaft/medizin/corona-krise-bringt-rekord-rueckgang-der-co2-emissionen-a-81f70390-624d-4717-ba35-f3b-c130ad8df> (accessed on 11.12.2020)

Further efforts are therefore required, both on the part of the German government (through ambitious targets and financial support via research programmes) and by business (through innovative business ideas and technologies), in order to achieve the 2030 climate targets and climate neutrality by 2050. As Chancellor Angela Merkel stated at the beginning of November 2020, the climate targets are not an obstacle to growth, but rather a driver of it and give rise to new market opportunities, including the use of renewable energies and technologies to increase efficiency<sup>172</sup>.

## 10.2 Promotion of CO<sub>2</sub>-neutral transport

The EU Commission's target for lowering CO<sub>2</sub> limits stipulates that new cars should emit an average of 15% less carbon dioxide by 2025, and 30% less by 2030. In addition, 30% of new cars should have electric or other alternative drive systems by 2030.<sup>173</sup> Electric vehicles can make a significant contribution to achieving the transport sector reduction targets (→ Figure 30).

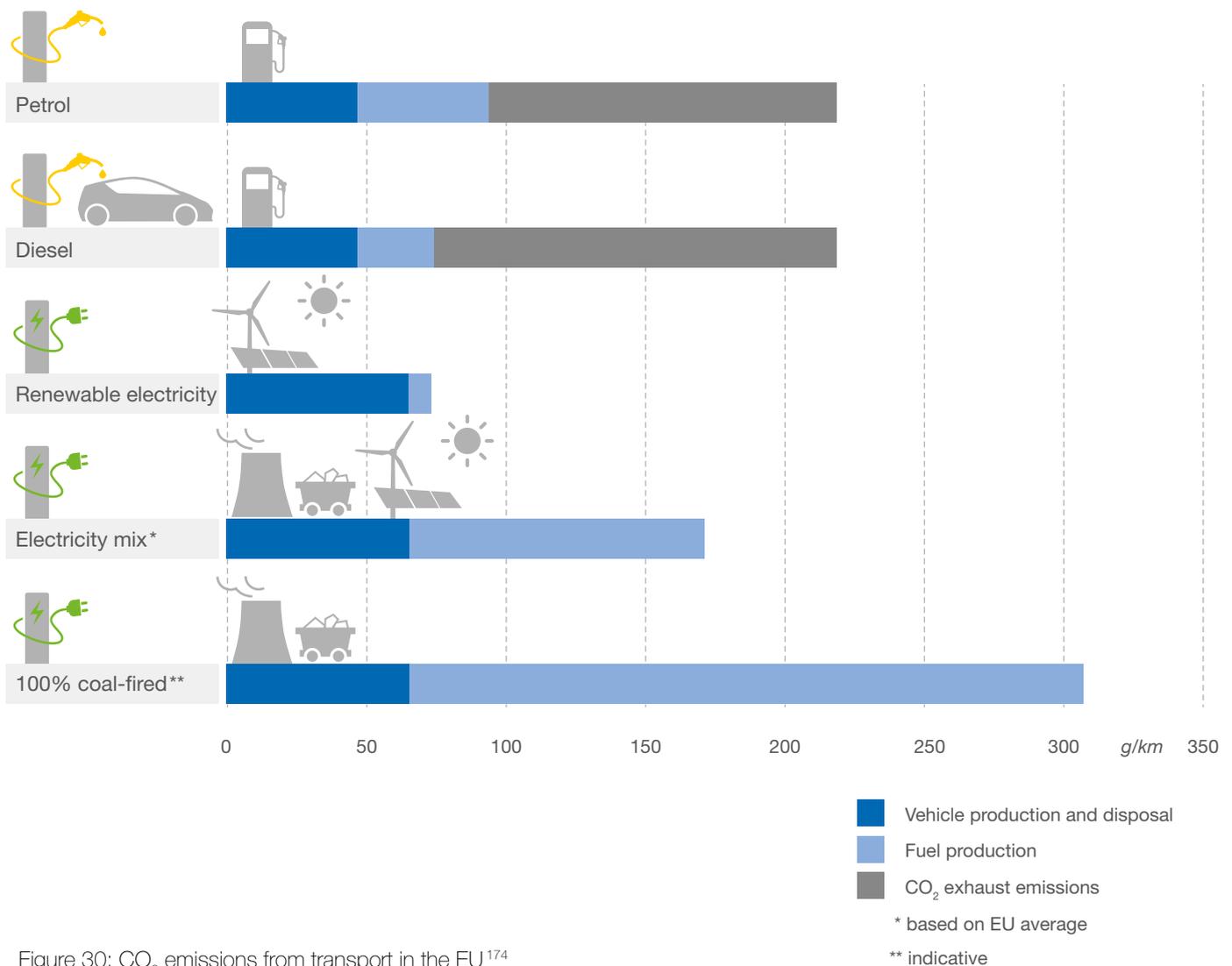


Figure 30: CO<sub>2</sub> emissions from transport in the EU<sup>174</sup>

172 <https://www.boerse-online.de/nachrichten/aktien/merkel-nennt-den-klimaschutz-einen-wachstumstreiber-1029771387> (accessed on 13.11.2020)

173 <http://www.manager-magazin.de/unternehmen/autoindustrie/co2-grenzwerte-eu-commission-will-reduce-co2-emissions-by-30-percent-by-2030-a-1177001.html> (accessed on 20.10.2020)

174 <https://www.europarl.europa.eu/news/de/headlines/priorities/klimawandel/20190313STO31218/co2-emissionen-von-autos-zahlen-und-fakten-infografik> (accessed on 20.10.2020)

Restrictions in the form of toll payments already exist in many variants throughout Europe. They are usually linked to road maintenance costs or are intended to limit high numbers of tourists. Similarly, traffic can be avoided by imposing time-based or local restrictions on certain vehicles. These indirect restrictions are not aimed directly at electromobility. But by introducing exemptions for battery-electric vehicles, these regulations can also encourage the purchase and thus the use of electric vehicles.

The direct promotion of battery-electric vehicles, as encouraged by the Federal Government in an amendment in summer 2020, also provides incentives for electromobile transport. The increase of the e-car subsidy to a maximum of €9,000 until the end of 2021 came into force on 7 July 2020 and applies retroactively to car purchases made since 3 June 2020. In addition, everyone – including the buyers of such vehicles – benefits from the reduction in VAT from 19% to 16%, which is limited until the end of 2020. There are more than one hundred German government subsidy programmes for electromobility, some of these also covering the necessary infrastructure: there are different funding opportunities and subsidy levels depending on the region, the object and the applicant (i.e. private or business customers).

After the 4-year introductory phase, the registration figures for e-vehicles rose noticeably since the subsidy in the form of the innovation premium was increased in summer 2020. By the end of September 2020, the Federal Office for Economic Affairs and Export Control had received exactly 284,482 applications for funding since the introduction of the environmental bonus in July 2016, with 27,436 arriving in September 2020 alone. Pure e-cars accounted for 176,298 applications, plug-in hybrids for 108,015 and fuel cell-powered hydrogen electric vehicles for 169.<sup>175</sup>

Compared to the same month last year (with lower funding; 1,951 PEHVs, 0 FCEVs, 4280 BEVs), this corresponds to a roughly 340% increase in applications<sup>176</sup>. It is not yet clear whether the current growth in electric vehicle numbers will be sufficient to reach the target of 10 million e-vehicles in 2030.

The extension of the innovation premium until 2025, which was resolved in November 2020, could further consolidate the trend towards electromobility.

Further direct monetary support for electric vehicles came with the expiry of the non-combination rule on 16 November 2020. This had only been introduced in the summer of 2020. As a result, different funding programmes can now be combined with each other under certain conditions. This leads to a higher overall subsidy and can make electromobility even more attractive in the eyes of users.<sup>177</sup>

The German government also provides direct financial support for the use of and research into alternative fuels (→ Chapter 3.3). The Federal Ministry of Education and Research funds research and development work on electricity-based fuels. Production processes and the use of oxymethylene ether (OME) in particular are being tested and optimised in the “Nachhaltige Mobilität dank synthetischer Kraftstoffe” (NAMOSYN – Sustainable Mobility Based on Synthetic Fuels) funding initiative, for example. In its energy research programme, which includes the “Energy Transition in Transport” research initiative, the Federal Ministry for Economic Affairs and Energy is funding 16 research networks, including over 100 participating research groups and industry partners. All projects focus on the production or use of innovative, electricity-based fuels such as methanol, ethanol, oxymethylene ether (OME), paraffin, synthetically produced natural gas and biogas containing a proportion of hydrogen. Some of these alternative fuels can be blended directly with the fuel used in today’s cars, trucks, planes or ships. Others require adaptation of the engine design.<sup>178</sup>

As part of its International Climate Initiative (IKI), the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety is funding feasibility studies and the construction and operation of PtX plants in Brazil, Morocco, South Africa and Argentina/Chile to test the sustainable and large-scale production and use of PtX. Up to 1.3 billion euros will be made available by the Energy and Climate Fund from 2020 to 2023 for the development and promotion of plants for the production of electricity-based fuels, explicitly including those for aviation. Funding programmes being developed focus on market ramp-up, but also on research and development. Increasing international interest is also giving rise to industrial policy opportunities for Germany (technology leadership), which can be addressed within the framework of international energy partnerships.<sup>179</sup>

175 <https://www.autobild.de/artikel/e-autos-infos-zur-innovationspraemie-kaufpraemie-umweltbonus-foerderung-8535657.html> (accessed on 27.10.2020)

176 <https://www.electrive.net/2020/11/02/318-694-umweltbonus-antraege-bis-ende-oktober/> (accessed on 1.12.2020)

177 <https://www.electrive.net/2020/11/04/umweltbonus-bmwi-hebt-kumulationsverbot-zum-16-november-auf/> (accessed on 1.12.2020)

178 [https://www.energiesystem-forschung.de/foerdern/energie-wende\\_im\\_verkehr](https://www.energiesystem-forschung.de/foerdern/energie-wende_im_verkehr) (accessed on 9.11.2020)

179 <http://dipbt.bundestag.de/doc/btd/19/186/1918648.pdf> (accessed on 15.9.2020)

# 11. Challenges facing the ICT for Electromobility Technology Programme until 2030

Future ICT for Electromobility Technology Programme project areas can be determined and ideas for further fundamental work can be identified (outside the ICT programme, too) from the various aspects and potential development directions which have been presented for the transport sector and on the basis of the logistics and mobility services being provided.

## Vehicle communication and data

The way in which vehicles communicate with their environment and make use of the generated data represent possible future orientations. The data generated in and by vehicles, plus its use and handling, are the focus of the “Mobility Data Space” project of the Federal Ministry of Transport and Digital Infrastructure. The acatech-led project aims to implement the first

applications by the ITS World Congress in Hamburg in mid-2021. Here, the aim is to mesh very closely with other future projects in order to draw the greatest possible benefit from the experience gained and the money spent so far.<sup>180</sup>

Potential electric vehicle communication methods based on information and communication technologies include (→ Figure 31):

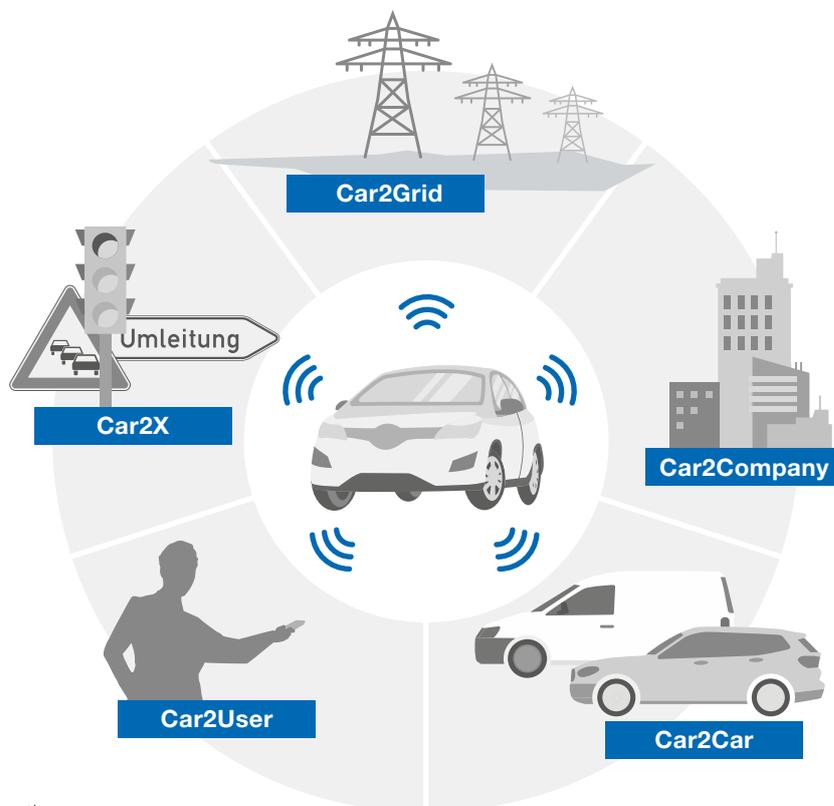


Figure 31: Car2... communication

180 <https://www.acatech.de/projekt/datenraum-mobilitaet/> (accessed on 2.12.2020)

- **Car2Car** – Platooning, e.g. greater utilisation of existing infrastructure, optimisation of traffic flow
- **Car2X** – Traffic lights, traffic signs, e.g. optimising and controlling traffic flow
- **Car2User** – Reporting of pick-up and drop-off requests, coordination / requests for / payment of driver services
- **Car2Grid** – Optimisation of charging, grid-friendly harmonisation with user behaviour
- **Car2Company** – Vehicle data transmissions to home company, e.g. for re-routing (also includes Car2Grid / user communication information)

The vehicles of the future will generate masses of data. The basic precept for vehicle communication and associated data should be: as much as possible – as little as necessary. It is important to use and handle the relevant data (for the provision of energy, for example) with care, in order to protect the consumers. At the same time, however, the goal is to obtain the greatest possible benefit for each individual and ideally also for the entire economic and energetic system. Digitalisation generates more data overall on the vehicles, the consignments and the passengers etc. Coordinating all this data and providing a service that is optimised in terms of energy, economics and time efficiency will be a major challenge in the future.

### Vehicle utilisation

Increasing vehicle utilisation levels can help to transport the steadily growing amount of goods with the same number of vehicles, thus counteracting any potential traffic gridlock in (inner) cities.

Vehicles (and drivers) are viewed as containers that can be loaded by different organisations. The aim is to achieve maximum utilisation of each vehicle in each 24 hour period, seven days a week. Solutions based on fleets of vehicles publicly owned by the municipality are conceivable for this purpose, for example. The last mile is outsourced by the previous transport service provider to these vehicles. This would require transshipment points in the suburbs in order to transfer goods from long-distance to last-mile vehicles (→ Chapter 9.4).

In addition, this solution also requires inner-city handling facilities for deliveries within the urban area. A second application for increasing the vehicle utilisation levels in the logistics sector is the simultaneous or downstream multiple use of vehicles for different groups of goods in the form of hybrid, multi-use or composite deliveries. This would allow the combined delivery of newspapers and post, for example, in the morning. At lunchtime and in the evening, it would be used for food deliveries. And in the afternoon and evening hours, parcels and perishable goods such as flowers and food could be delivered.

Passenger vehicle utilisation should also be further optimised. For example, current shuttle solutions such as the BerlKönig service allow the automatic combination of journeys of otherwise independent passengers. Shuttle vehicles, however, are perceived more as competition to regular taxi services, and are used as such. As a result, they are viewed critically by both established mobility service providers and the German government<sup>181</sup>. Ingenious solutions will be necessary if they are to establish themselves in the long term. These concepts could include feeder or distribution services which combine as many individual journeys as possible in order to increase the vehicle utilisation rate. They must offer clear added value for users, for example by providing access to peripheral urban areas which currently have no scheduled services.

### Development of charging technologies

Automated conductive charging solutions will yield only a very limited range of benefits. As a premium product, the necessary expenditure must be offset by serving suitable circles of users. These could be those seeking combined charging and parking solutions, for example, in which the vehicle is parked automatically, similar to a high-bay warehouse, with the charging current also being supplied automatically. Such a special form of “vehicle storage” could at the same time yield added value by making more intensive use of urban space for this purpose than has been the case up to now. This would free up valuable inner city space for alternative use.

181 <https://www.berliner-zeitung.de/mensch-metropole/dem-berlkoenig-der-bvg-droht-schon-bald-das-aus-li.75611> (accessed on 13.11.2020)

## Reform of the Renewable Energy Act

Reform of the EEG beyond the current cabinet draft is necessary to exploit the full potential of existing solar installations and to support the mandatory solar installations on new building roofs<sup>182</sup>, as planned in Hamburg. The necessary reforms should therefore include the following:

- Private solar power producers (including wind and hydro power producers) can sell their self-produced, ecological electricity to their neighbours at low prices (i.e. well below current market prices). In return, this electricity should be fully exempted from the EEG levy.
- In future, housing associations, housing cooperatives and landlords will be allowed to pass on the green electricity generated on their own residential properties and associated buildings and surfaces to their members and tenants at favourable rates without an EEG levy, thereby lowering their electricity prices by a corresponding amount.

Even if the ICT for Electric Mobility Technology Programme has no influence on the corresponding legislative procedures, it is at least possible to provide substantive support and to develop prototypes. By 2020, content-support had been set up as a successful instrument (particularly with regard to legal frameworks) in the form of workshops and recommendations on measurement and calibration law, among other things. Prototypes of solutions, such as those developed in the projects funded by the Technology Programme, can serve as examples, new impulses and models for future amendments of the legal framework.

## Demand-driven development

The needs of the various stakeholders should always be at the centre of the considerations. The network of actors and issues is closely interwoven, meaning that any demand for mobility is inevitably linked to a corresponding demand for electricity. Investigations need to be conducted at an early stage to determine e.g. the share of direct electricity use in electromobile vehicles and the share of electricity use (via hydrogen, for example) in fuel cell vehicles. This is because these shares can be used to calculate the demand for domestic, renewable energy, the demand and the costs for corresponding energy imports<sup>183</sup>, and consequently also the effects on the electricity grids. In the long term, it is also important to make more detailed use of the energy production forecasts. The underlying

weather models are continuously being optimised. The integration of current weather data and high-resolution forecasting models can contribute to the optimal direct use of renewable energy because its use can then be planned more accurately. In particular, it is not possible to draw conclusions about the provision of the various energy sources and the production of the electricity required for mobility and logistics within a time horizon of ten years. Instead it is more important to focus on the longer-term perspective of 2050 because the complexity of the corresponding research projects and the resulting investment precludes their realisation in the short term.

## Success monitoring

In order to select the economically, ecologically and socially most viable solutions, it makes sense to conduct early tests in innovation projects with correspondingly realistic "pilot applications", such as those carried out within the framework of the ICT programme. However, long-term monitoring of the implemented projects is necessary here, too. Only later success monitoring – from a sufficient distance and under consideration of the actual conditions – can determine to which extent the project has matured into a genuine innovation within the market.

182 <https://www.handelsblatt.com/unternehmen/energie/erneuerbare-energien-was-eine-solarpflicht-fuer-neubauten-bringt-und-was-daran-kritisiert-wird/26252848.html?ticket=ST-1240803-KUN2t0LzorcBvDKdvzs-ap4> (accessed on 2.11.2020)

183 Christian Breyer, LUT University and Global Alliance Powerfuels, presentation given at the Hydrology Online Conference (8.10.2020)

# 12. Outlook and conclusion

With a narrow majority, MEPs passed a resolution in mid-October 2020 which further tightened their previous demands. The aim now is now for a 60% reduction in CO<sub>2</sub> emissions by 2030.<sup>184</sup> The previous target of 40% had already been tightened by the Commission to 55% (in each case in comparison to the year 1990). Business representatives have described the legislature's increasingly ambitious climate targets at the regional, national and international levels as anti-business, whereas independent non-governmental organisations have welcomed these steps.

“Business as usual” is no longer an option with regard to overall greenhouse gas emissions. Instead, people are now asking: by when and by how much. But the further climate change progresses, the more dangerous the associated impact will be on nature as the basis of human life.

The ICT for Electromobility Technology Programme of the Federal Ministry for Economic Affairs and Energy has been funding ambitious projects in the field of electromobility for 10 years. Considerable efforts will be needed to achieve the climate targets. Electromobility can make a decisive contribution to this, as transport is one of the most energy-intensive sectors.

Economies and societies in general are currently in a state of upheaval which, regardless of the acute threat from the corona virus, will result in far-reaching changes to the energy industry, logistics and mobility. Renewable energy must be made less susceptible to the volatility of its availability. Batteries have been in use for some time now as a storage medium. It is important: to ensure that the resulting electricity is distributed effectively via the grid; to develop new battery types in the long term; and to increase the sustainability of the batteries through secondary use, where possible. Hydrogen, as a storage form for electricity produced from renewable energies, suggests itself as a green alternative to the present use of diesel and petrol, especially for long-distance transport.

Setting the course for new technologies, testing them at an early stage and implementing them in prototype projects within a realistic environment are essential ways in which Germany can ensure its future success as a business location. The technological transition has already begun and will become increasingly evident in the next ten years. Accordingly, it remains important to

test new technologies and develop application scenarios for them.

It is already apparent that the technological transformation from the classic internal combustion engine of the last hundred years to environmentally friendly drives will not be based on any simple one-to-one exchanges of technology. Rather, different options will be available for different applications. Prudent selection of the optimum solution will help ensure maximum benefit.

In order to leverage these benefits, the ICT for Electromobility Technology Programme aims to continue to explore ways of exploiting new electromobility-related technologies. The knowledge generated in the research projects constitutes a central building block for safeguarding Germany as a business and knowledge location and thus enable it to secure its economic, ecological and social future in 2030 and beyond.

184 <https://www.handelsblatt.com/politik/international/kampf-gegen-die-globale-erwaermung-eu-parlament-verschaerft-klimaziel-auf-minus-60-prozent-heftige-kritik-aus-der-wirtschaft/26253056.html?> (accessed on 16.10.2020)

# List of Figures

Figure 1: Key themes in 2030 meta-study	2
Figure 2: Potential for CO <sub>2</sub> reduction	4
Figure 3: Final energy consumption in transport sector by energy source	5
Figure 4: CO <sub>2</sub> emissions in the EU	6
Figure 5: Number of electric vehicles – “Global” and “European”	7
Figure 6: Structure and functioning of a lithium-ion cell during discharging	8
Figure 7: Phase diagram of mixtures of the transition metals Ni, Co and Mn	9
Figure 8: Battery cell production in Germany	11
Figure 9: Colour code for basics of hydrogen production	13
Figure 10: Comparison of drives in electric and fuel cell vehicles	17
Figure 11: Battery versus hydrogen fuel cell: Application scenarios in vehicle drives	18
Figure 12: Overview of alternative fuels	19
Figure 13: Comparison of conventional and alternative fuels	21
Figure 14: Drive technologies of the future	22
Figure 15: Energy market 2030 (extract focusing on e-mobility)	25
Figure 16: Energy scenario 2030	28
Figure 17: Probable use of charging technologies in 2030	30
Figure 18: Overview of charging options	31
Figure 19: Concepts for consumer–power grid networking	33
Figure 20: Phased approach for autonomous driving	36
Figure 21: Future delivery options	37
Figure 22: Transport modes and drive energy	39
Figure 23: Logistics actors	42
Figure 24: Flybot visualisation	45
Figure 25: Advertising pillar logistics visualisation	46
Figure 26: Parcel concierge visualisation	48
Figure 27: Last Mile Market visualisation	49
Figure 28: DBee Logistics visualisation	50
Figure 29: Dimensions for logistics scenarios 2030	51
Figure 30: CO <sub>2</sub> emissions from transport in the EU	54
Figure 31: Car2... communication	56

VDE Verband der Elektrotechnik  
Elektronik Informationstechnik e. V.

Stresemannallee 15  
60596 Frankfurt am Main  
Tel. +49 69 6308-0  
[service@vde.com](mailto:service@vde.com)  
[www.vde.com](http://www.vde.com)

**VDE**