Netherlands Knowledge Centre for Underground Space and Underground Construction

Long-term vision on tunnels in the Netherlands

Table of contents

Chapter 1 - Introduction

Tunnels have caused many a headache over the past ten years, but the introduction in 2012 of the new law on tunnels and the Dutch National Tunnel Standard (LTS) has at last brought 'calm' into the tunnel sector. Both clients and contractors have become more professional as a result of their involvement in the development of the LTS and now work closer together. The time has now come for the next step: the development of a long-term vision on tunnels.

We are faced with a huge renovation task. The position of tunnels in their immediate environment and their network is changing, the issue of sustainability is coming to the fore and increasingly higher demands are placed on the reliability, availability and disturbance limitation of tunnels throughout their entire life cycle. In addition, developments in the tunnel sector are determined by a broad social and technological context. We will have to make choices and decide what we want and must influence, what developments we want to help shape and what developments we consider as given.

In order to formulate a long-term vision, we need answers to the following questions: What challenges are we facing, what social and technological developments are of relevance to the tunnel sector, what aspects are we able and willing to control and how are we going to do this?

The main question is: In what context will tunnels be operating in the future and what steps can we take now to prepare ourselves for that future?

1.1 Method

Tunnel managers, clients, market parties and other stakeholders in the COB network have mapped technical and social developments that will be important for the construction and maintenance of tunnels in the future. This document is a report on a comprehensive consultation round held in 2016. The 'Diner van de Ondergrond' ('Underground Dinner') on 20 June 2016 was the first step in that process. Numerous experts from inside and outside the COB network have been consulted since. The long-term vision has also been discussed within three COB platforms, a discussion group of experts from Rijkswaterstaat (Dutch infrastructure agency) and the Knowledge Platform on Tunnel Safety (KPT). No international experts have yet been consulted, but this option remains open for the follow-up phase.

All consulted experts and members of the above-mentioned discussion groups, nearly two hundred people, were sent an earlier version of this document for review. Their comments were incorporated in the version discussed with the COB Programme Board on 15 November 2016. The feedback from the Board members helped draft the present document, which was presented at the COB Congress on 8 December 2016.

In early 2017, this vision will be turned into a concrete action program, which will, where possible, reflect the knowledge questions identified in the COB programme for 2015-2020. The network will again be involved closely in line with the COB method: from observation to the articulation of questions and from testing to validation together with the network.

1.2 Objective

Through this long-term vision, the COB wants to support and challenge all stakeholders, namely the government, market, science and society. The objectives are:

1. **Sketch, challenge and inspire a future.**
   The future of the sector, now just a dot on the horizon, mobilizes us and gives us a common objective. The last chapter of this document contains an outline of this vision, that is, a long-term vision on tunnels.
2. **Determine a (knowledge) position.**
   The long-term vision must help us shape the changing positioning of underground construction in the (academic) world. Apart from technical and civil construction issues, we are becoming increasingly closely involved in integrated tasks in the fields of safety, spatial integration, value creation, design, reliability, maintainability, availability and durability. The position of The Netherlands may be quantitatively modest, but qualitatively The Netherlands has achieved a prominent position in terms of demonstrable safety, immersed tunnels, project management and the environment. However, the broad subject of tunnels does not have an academic foundation anywhere in The Netherlands or elsewhere in the world, which opens it up to new opportunities worldwide. Through this long-term vision, we want to achieve a position based on knowledge and innovations, to implement the best applications in The Netherlands and to create opportunities for companies to export such applications.
3. **Apply focus to the joint tasks surrounding tunnels.**
   The complexity of all the issues surrounding the subject of tunnels presents a certain challenge and, at the same time, there is a risk in taking joint action. Many developments are beyond our influence and, although we could get involved in many developments, we cannot afford to take a shotgun approach. With this vision, we want to define our objective as clearly as possible and propose how to achieve it together as effectively as possible.

In the long-term vision on tunnels in the Netherlands, COB explicitly limits itself to the construction, management, maintenance and renovation of road and rail tunnels in The Netherlands. Our time framework is 2050. Based on the long-term vision, COB will make recommendations and direct the development of that vision into action plans, explorations, projects and so on.

Chapter 2 - What are we up against?

This chapter outlines the social and technological developments that the tunnel industry should be prepared for. These developments largely determine our playing field in the world in which we will have to operate. If we do not actively determine our position, then we will only be able to react to events. And that would be a pity, because the changes we are facing offer many opportunities, not only threats.

2.1 Demographic developments cause space constraints

Demographic developments are having a direct effect on available space and mobility in our country. Underground construction is a vulnerable sector. Its profitability and added value depend heavily on space constraints. In the long term, we cannot assume that space constraints will continue to exist everywhere. The **PBL Netherlands Environmental Assessment Agency** envisages regional differences, as evidenced by the report 'The Netherlands in 2040: A country of regions – Spatial Outlook 2011' and the Regional population and household projections 2016 by PBL and Statistics Netherlands (CBS). An important conclusion is that various urban areas in the Randstad will continue to grow whereas a number of peripheral areas, such as Central Limburg, Zeeuws-Vlaanderen and East Groningen, will shrink. An equally important finding is that there is uncertainty regarding many regions, whether they will shrink or grow. And the further away in time, the greater that group of uncertain regions becomes.

Of the expected growth of the Dutch population – almost 950,000 people between 2015 and 2030 – almost three quarters of that growth will take place in the larger municipalities, which will get an extra 100,000 or more inhabitants. The largest growth is expected in the four major cities, which will grow on average by 15% between 2015 and 2030. Amsterdam, Rotterdam, The Hague and Utrecht together will account for one third of the Dutch population growth by 2030. There are other strong growers in the west of the Netherlands, such as Almere, Haarlem, Haarlemmermeer and Amersfoort. Various towns situated in the vicinity of the major cities are also growing strongly, such as Diemen near Amsterdam and Rijswijk near The Hague. In the south of the Netherlands, the growth is led by towns in Brabant, such as Tilburg, Eindhoven, Den Bosch and Breda. In the east of the Netherlands, the populations of Zwolle, Arnhem, Nijmegen and Ede continue to demonstrate a strong growth. In the north, Groningen and Leeuwarden are also undergoing a significant growth.

2.1.1 Importance for tunnels

» More integration.
» More value.
» Other dominant clients.

The starting point in the 'City and infrastructure: transformation of motorways and the environment' study of the **Council of Government Advisors** is that you first look for space for new spatial developments in the city, and only if space is not available there you look at areas around the city. The construction of road and rail tunnels and roofing over roads and railways can generate additional space. Building on top of tunnels should not be a problem any more. Tunnels, therefore, play a role in strengthening the business climate and can add value to cities.

Underground space use, in this case a tunnel, helps create new available space above ground and thus improves the quality of the living environment. We have seen in recent years that tunnels are no longer seen as separate objects, but are being developed as part of a larger whole with bigger ambitions, such as A2 Maastricht, Spoorzone Delft and Zuidasdok. In addition to making cities more accessible, with the functionality, availability and safety of tunnels being an integral part of such accessibility, the quality of life becomes the fourth pillar in the decision-making process on whether or not to build new or renovate the existing tunnels.

As space constraints predominantly play a role in urban areas, cities and urban partnerships will increasingly become clients in the procurement of new tunnels. The government will assume that role in new tunnel projects relatively less often.

2.2 Increasing mobility

Population growth in cities will mean a corresponding growth in mobility. Dr **Walther Ploos van Amstel**, lecturer in City Logistics at the Amsterdam University of Applied Sciences, notes that the mobility needs of citizens do not decrease. Dr **Carlo van de Weijer** (director of Smart Mobility at the Eindhoven University of Technology, global IT expert with TomTom) does not see any trend break in the growth of mobility. In the long-term scenarios of the 'Toekomstverkenning Welvaart en Leefomgeving' or WLO (futures study on prosperity and the living environment), 30-60% more car kilometres are taken into account until 2050. Freight transport will also increase by 20-50% by 2050.

Traffic and transport are an important source of CO_2 and particulate matter emissions. Between 1990 and 2013, emissions from traffic and transport increased from 31 megatons to 36 megatons of CO_2. The research conducted by TNO and Connekt, commissioned by the **Topsector Logistiek** (leading sector logistics), shows that if unchanged the existing policies will cause the actual increase in CO_2 emissions by the transport sector to overrun by a factor of six (see FIGURE 1).

Figure 1: CO2 emissions by the transport sector vs the desired level of emissions (Source: TNO/Connekt commissioned by Topsector Logistiek)

The **Ministry of Economic Affairs** reported in October 2016 that The Netherlands now has 95,000 electric cars, of which 11,402 full and 83,686 partial ones such as plug-in hybrids, and 24,500 charging points have also been installed. For both indicators, the Netherlands is among the world's top five players. The **ING Economic Bureau** previously estimated that the market share of fully electric cars in the registrations of new passenger cars in the Netherlands would reach 7% by 2020. This estimate was raised to 10% in September 2015. This share is predicted to rise to 25% by 2025. It is expected that the rate of increase will speed up after that, but its exact scope remains uncertain: 'After 2020, full electric cars will conquer the market more and more in their own category. Their market share will develop rapidly. Eventually, it will catch up with the fuel engine,' according to Max Erich of the ING Economic Bureau.

2.2.1 Importance for tunnels

- » Safety challenges will change.
- » The space next to and on roads is almost the only place where a city can grow. This demands...
  - … smart multiple use of space, and
  - … smart integral design of tunnels in their environment.

Additional mobility pressure arises in cities because a relatively large part of the transport time is spent within cities. Of all car kilometres in the Netherlands, 21% is driven within the built-up area, with 39% of the total travel time is spent within the built-up area (see FIGURE 2).

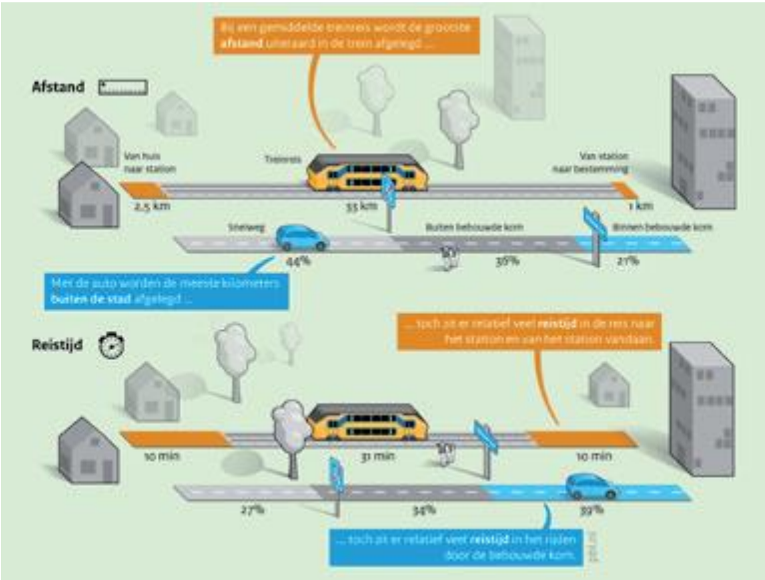

Figure 2: More kilometres outside the city, most travel time within the city. (Source: PBL Netherlands Environmental Assessment Agency)

Apart from the autonomous growth of car mobility, there has also been an increase in small-scale freight transport, as more and more purchases are being made on the Internet. In cities especially, this increase leads to extra congestion, CO_2 and particulate matter emissions. Better utilisation of underground space and the utilisation of space around and on motorways will be necessary to make and maintain the habitability and economic viability of cities. The new fuels and modes of transport will create additional safety challenges. Not only in tunnels, but within the entire urban system. It is no longer about tunnel safety, but about the integral safety within the city.

2.3 Everything becomes smart

Decisions are made and processes managed more and more on the basis of big data flow analyses. This also applies to the management of traffic flows and the optimal use of infrastructure, whereby vehicles moving within the infrastructure are part of the system/network. For example, data from cars is linked to that of the infrastructure, including tunnels.

Vehicle control will change over the years. Initially, drivers will receive support in performing their driving tasks and, over time, inbuilt systems in cars will fully take control. This development will lead to smart road systems/networks. To ensure that self-driving vehicles can distinguish between different objects, it will be necessary in some cases that nearby objects share information. It is a mistake to think that all the required intelligence will be fully inside the vehicle. The expectation is that some intelligence will be needed inside tunnels, but it is still too early to say in what area that will be. It is also expected that there will be a transitional period during which several systems will coexist. During the transitional period, in addition to current safety systems, GPS and communication systems may also be incorporated in tunnels as well as in-car systems.

Dr **Wout Broere**, assistant professor of Underground Space Technology at Delft University of Technology, says: ‘We imagine that in 20 years’ time we’ll all be driving in self-driving cars. But that does not mean that the infrastructure will have gained sufficient capacity by then to allow cars to drive closer together. Because of the required safety margins, the distance between cars will actually be greater than at the moment. We must take this into account, especially during the transitional phase. It is wishful thinking that self-driving vehicles already have a positive impact on today's task.’

Carlo van de Weijer (director of Smart Mobility at the Eindhoven University of Technology, global IT expert with TomTom) says: ‘Assume that everything you want to know in order to manage infrastructure and traffic systems will become available through cars. You must be prepared for that in time. The legislator tends to lag behind technological developments.’ He tempers the expectation that we will have a coherent, centrally managed mobility network in the future: ‘Self-driving cars do not lead to an all-encompassing system in which cars function as railway carriages. I do not believe that citizens accept heavy top-down control. Traffic becomes a self-governing whole of well-informed and autonomously operating individuals. In some situations, these individual vehicles will cluster together if that leads to a better journey.’

During the COB Mini Conference on Big Data on 26 October 2016, **Jasper Maters** MSc, global account manager at Google, shared his insights into the way still to go: ‘Up until now, we have a million miles of experience with autonomous cars. The expectation is that after 10 billion test miles, we will have enough data to allow a car to operate properly and safely. Communication between cars and infrastructure is part of that. Cars will always be updated wirelessly with the latest information and thus become ever smarter.’

2.3.1 Importance for tunnels

- » Tunnels will also become smarter, but system thinking and working will be necessary.
- » We should not become paralysed by the great uncertainty about the pace and the degree of change.
- » Tunnels follow developments, they do not lead them.

What does the trend towards an increasing use of the Internet of Things and big data mean for tunnels? Tunnels will become part of smart cities, where all kinds of objects collect data. Analysis of that data provides opportunities to improve flow and safety in tunnels, save energy and improve services. But there are also risks. Information systems can, for example, be hacked. Attention to privacy and cybersecurity is therefore a prerequisite.

The experts who have been consulted warn against hasty decisions and, above all, advise to ensure flexibility. Developments are going so fast that, within a relatively short period, there will emerge numerous applications which we cannot yet envision. We do not yet have idea of the duration of that transitional phase. There is still much uncertainty about the effects of the smart society developments and the rate at which changes are taking place. When constructing and renovating tunnels, where the lead time from conception to realisation can take 10 years or more, the aforementioned uncertainty can have a paralysing effect. We can say with absolute certainty that the tunnels being devised today will no longer meet the requirements and expectations 10 years from now. We also know that due to automation tunnels will increasingly be part of traffic networks and systems.

It is not yet clear how the development of self-driving cars will proceed. It seems right to assume that in the future it will be possible to drive cars closer to each other. As a result, the capacity of roads will increase and lanes can become narrower. However, it is unknown when that will become possible. It is not yet possible to predict either when smart in-car safety systems can (partially) take over the role of safety systems in tunnels, and if specific tunnel safety systems will still be required. Another question is whether it will be possible to use systems developed for tunnels in the future for integral road systems. And does the rapid development of sensor technology offer opportunities to optimise tunnel management and increase availability? As we do not yet know the answers to these questions, it makes sense to organise the whole tunnel construction and renovation process in such a way as to make interim adjustments possible.

2.4 The human factor

There is a trend to increasingly take the human factor into account. All technology in the world is not able to fully control that factor. We can distinguish three groups: citizens (environment), users and administrators/operators.

Citizens are becoming increasingly articulate and can organise themselves fast through social media. This can lead to a more active and sometimes more activist role of stakeholder organisations. This must be properly considered when constructing and renovating tunnels. For example, citizens emphatically claim the role of stakeholders in plans for large (infrastructure) projects. At the same time, they expect more for less and demand that community money be spent effectively. An important desire on the part of citizens is to reduce disturbances. This concerns disturbances during the execution of work, derived disturbances due to the realisation of projects, disturbances for users and derived disturbances for the environment during use.

As tunnel **users**, citizens want to be served better and their concerns to be taken away. They want good and timely information about the traffic flow and tunnels in which they would feel safe and comfortable. This aspect is still under development. Tunnels are opened with the human factor as a dominant aspect in the risk analysis, but we have no tools to play with or control this aspect. At the same time, the possible influence of user behaviour with a view to the sustainable use of tunnels is barely or never taken into account. For example, it is still unusual to test the design and opening of road tunnels with real road users. We still have far to go here.

Tunnel **administrators and operators** will have to learn to handle the rapid developments in smart mobility and their changing position as a puzzle piece in the (network and environment) system. It is also clear that a safe working tunnel will always be a combination of technology, other measures and the operator who will have to handle them in a smart way. The densification of cities, their expansion over motorways and the associated integration issues will mean that the standard tunnel with standard control and operation will, perhaps, be the desired situation, but reality will require more customisation. This also makes the role of the operators and drivers more crucial.

2.4.1 Acceptance of big data / 'the Internet of Events'

In the developments that become possible with the use of big data, human acceptance is a decisive factor. The 'Internet of Events' and big-data developments enable objects to communicate with each other autonomously without human intervention. Potentially, IT systems will take over more and more of people's tasks and activities. The discussion of what this means for people and organisations has only just begun. Where is the balance between supporting technology and controlling technology in people's perception? How will we ensure that we take the human factor sufficiently into account in the striving towards process optimisation (more reliable, safer and maximum available infrastructure)?

The responses of participants in the COB Mini Conference on Big Data show that the effective use of big data is not yet a matter of course. There is a kind of chicken-and-egg problem: everyone is enthusiastic about big data, but the perception is that parties only want to go ahead with it when it becomes clear what it produces. Participants who are further in the process of applying big data often encounter resistance because the prospect of more effective and efficient work may entail job losses. Experience also shows that organisations do not want to share their data because they do not want to give up their (commercial) advantage ('If I shield my data I have more than the others.'). At that conference, **Jasper Maters** suggested that Google itself innovates based on the analysis of all available data. It appears that in their daily practice the conference participants tend to proceed with a particular objective in mind and that they concentrate on collecting specific data (for example by means of tunnel sensors).

As for the acceptance of the use of big data, we do not only deal with professional decision-making, construction and maintenance, but also with operators/administrators and tunnel users.

We must understand that it is not self-evident that the potential benefits of using big data will actually be achieved. There may potentially develop a friction between central and individual optimisation. The COB can play a part in the process of fostering awareness needed to get parties involved.

2.4.2 Importance for tunnels

- The development of technology makes it even more important that the human factor be properly understood.
- Less disturbance becomes the norm; during construction, maintenance and operation.
- Users expect to be served and taken care of.
- This development enhances and speeds up the process from thinking in terms of objects to thinking in terms of systems and usage.
- The degree of the acceptance of new technologies has a major influence on the design and use of tunnels, but the current COB network has hardly any influence on that.

As technology options increase, users' expectations become bigger and evolve fast. They expect that traffic flow disturbances will be considered as avoidable in the future. It is no longer the user having to adapt to the network, but the network having to adapt to the user. Safety systems will move from prevention through signalling to prevention through prediction, whereby road systems, including tunnels, will be proactively communicating with road users and vice versa. These developments speed up the process from thinking in terms of objects to thinking in terms of usage.

Reducing and even eliminating disturbances will eventually become the norm. The impact that major infrastructural projects, especially in cities, still have on the quality of life, will no longer be acceptable in the increasingly busy cities. This applies to both construction and management, maintenance and renovation. The concept of availability, which until now we applied mainly to the object (the tunnel), acquires the broader context of 'availability of the city'.

Citizens will no longer accept that tunnels are treated as separate objects in the transport corridor. They will emphatically ask for an integrated area vision in which the tunnel should contribute to the optimisation of the quality of life in that area.

In addition, the role of the tunnel user (the motorist) will become increasingly important. We cannot predict to what degree new technology will be accepted. We will have to learn to understand how to influence the user's perception and what the human factor encompasses. That means the difference between smart design, management and maintenance on the one hand and high investment with low returns for the user on the other.

2.5 Climate adaptation policy

The government wants to protect The Netherlands against high tides, ensure adequate freshwater, combat soil subsidence and prevent flooding caused by severe precipitation, now and in the future. The Netherlands must be organised in such a way as to become climate-proof. We must anticipate the effects of climate change, including rising sea levels, changing precipitation patterns and heat stress in cities. The government's policy is central to the long-term vision on tunnels.

The **Delta Programme** has been developed to tackle the challenges of climate change. This programme focuses not only on the water safety task but also on the climate-proof use of space (climate adaptation) and promising combinations with other functions such as nature, living and working. There are opportunities to increase not only water safety, but also to improve the quality of the environment. A special part of climate adaptation is the question of how to deal with vulnerable and vital infrastructure.

2.5.1 Importance for tunnels

- Climate change makes the tasks for tunnels more complex, but also offers opportunities for generating added value.
- The approach to the climate task in the Delta Programme is the same as to the tasks for tunnels: tunnels, just like dikes, are crucial objects in which functionality, safety, availability and quality of life must be balanced.

The current climate adaptation policy leads to a solid task for tunnels. What is needed to keep tunnels dry in the increasingly heavier showers with a lot of precipitation in a short period of time? Can (some) tunnels act as temporary water storage facilities to prevent flooding in cities? And what measures are needed to ensure that tunnels can be used during a flood? In view of the tendency in the water safety policy to assume more self-reliance and evacuation of people from endangered areas, these are important questions. Evacuation routes from urban areas often go through tunnels that flood rapidly during a flood. Climate adaptation also raises specific technical questions. Developments in the field of renewable energy sources can affect the environment surrounding tunnels and specifically its underground part. For example, thermal energy storage in the soil causes stronger fluctuations in groundwater levels. The risk of tunnels lifting can therefore increase. This has already happened at the Koningstunnel in The Hague.

2.6 Government policy

In this long-term vision on tunnels we agree with government policy. That starting point is a condition to the success of the vision. We see across the board that the government withdraws leaving more to citizens and the market. We see that in legislation and the organisation of government agencies. We also see that the transition from fossil fuels to renewable energy sources and international climate agreements (see PARAGRAPH 2.5) directly affect all decision-making on infrastructure, including tunnels.

2.6.1 Organisation of the government

As a result of the introduction of the Environmental Planning Act, the **PBL Netherlands Environmental Assessment Agency** published the so-called policy letter in 2016, in which we can recognise the same integrated approach as the one the COB favours for the long-term vision on tunnels: 'The Environmental Planning Act calls for coherence and breadth in the National Environmental Vision, and the wide-ranging policy area of the physical living environment also needs direction.'

In the 'Towards a National Environmental Vision' advice, published by the **Council for the Environment and Infrastructure** in December 2015, one can read how the government should approach the changing role of citizens. The Council argues that the relationships between the initiator, the market, society and government need to be reassessed: 'The national government has correctly observed an increased self-reliance in society and the necessity to take a step back. [...] At the same time, consultation should also help to garner support for tackling the challenges, since the government can obviously no longer do this alone.' The Council adds a warning, which should also be taken into account in the long-term vision on tunnels in the Netherlands: 'The abstract and strategic character of the challenges being faced (such as climate change adaptation and the energy transition) will not resonate with all citizens. This fact puts into perspective what can be expected from the public and limits the ways public consultation can be organised.'

Meanwhile, we see a broad internal discussion at **Rijkswaterstaat** about the role of the organisation in an ever faster changing, more complex environment. 'Working from our purpose' is the red thread in the Rijkswaterstaat publication 'Horizon 2020'. It is the result of a dialogue between Rijkswaterstaat staff members about how the organisation can ensure that 'the internal procedures and statutory regulations [...] should serve the purpose and not be a barrier to our actions': 'What role do we see for us vis-à-vis market parties and knowledge institutes? Do we lead or facilitate? What is our added value? To get answers to those questions, we need people who want to think actively with us. And we especially need room to experiment. Not only time and resources, but also room in legislation, processes and internal regulations. We want a relationship between client and contractor with respect for each other's role and interests, and without legal hassle. We therefore need to listen to our partners carefully, give them confidence and be prepared to let go of familiar practices. Good communication is essential: informing each other well and timely, making realistic arrangements and being open to the possibilities.'

2.6.2 Energy agreement

Measures are being taken to combat the causes of climate change. For example, the Energy Agreement for Sustainable Growth assumes an average decrease in energy consumption by 1.5% per year, resulting in 100 petajoule energy savings by 2020. The share of renewable energy generation in total energy consumption should rise to 14% by 2020 and 16% by 2023.

In 'Towards a National Environment Vision', the **Council for the Environment and Infrastructure** lists what is needed in the longer term: 'The Netherlands is still heavily dependent on fossil energy. On the one hand, a transition to a sustainable energy supply is desired. To keep global warming within two degrees, the Netherlands must reduce CO_2 emissions by 80% by 2050 and largely switch to renewable energy sources. There must be a switch to renewable sources (geothermal energy, wind and solar energy, biofuels). On the other hand, the demand for fossil fuels can be limited by large-scale transformation of real estate (for example, energy-neutral housing) and the application of new technologies (such as electric driving, teleworking and teleconferencing). Smart apps can lead to a larger sharing and exchange economy, reducing the demand for energy. This energy transition has a major impact on environmental policy. Not only does the infrastructural energy network have to be adapted to a fine-meshed net for decentralised suppliers, but highs and lows in production (especially of wind and solar energy) must be met. In addition, space must be reserved for windmills, solar parks and large-scale production of biofuels.'

2.6.3 Importance for tunnels

- The new Environmental Planning Act gives a great impetus to tunnels as part of both the traffic system and the environmental system.
- There will be new players (both on the client's and contractor's side as well as on the customer's side).
- The tunnel as an energy guzzler requires special attention.

The new Environmental Planning Act will cause tunnels in the (urban) environment to be seen less and less as separate objects and increasingly as part of a larger (infra and spatial) system. This requires a firmer and different positioning of tunnels. Over time, the motives for building tunnels have become more diverse. That process is still going on. The first tunnels in the Netherlands were seen as isolated objects in a transport corridor constructed for the purpose of crossing a waterway or improving the flow of traffic. Meanwhile, there are more reasons for building tunnels, such as unifying cities, allowing for new aboveground functions and enhancing the living environment. These social tasks play a part in the replacement and renovation tasks for the coming decades and affect the construction and renovation of tunnels.

By considering tunnels as part of a complex environment, the process of design, construction and management changes strongly. Tunnel projects grow into integral, complex tasks with a multifunctional, multidisciplinary, multi-actor and sometimes multimodal character. The number of factors that need to be taken into account grows exponentially.

The changing role of the government implies greater responsibility for the market. There will be more and more partnerships between different authorities and the market for large infrastructural projects.

Another important question is how to reduce the high energy consumption in The Netherlands. The transition from fossil energy to renewable and sustainably generated energy has an impact on traffic and on the design and management of tunnels. For example, we will have to deal with cars powered by other energy carriers, such as hydrogen (with an electric or internal combustion engine), or electric cars powered by a battery. New fuels have an impact on safety requirements. The energy transition also offers opportunities in the form of additional functions for tunnels, such as energy generation and storage, thereby increasing the feasibility of new tunnels. For the existing and new tunnels, energy reduction is becoming an increasingly important component in renovation, management and maintenance.

The task for tunnels is very topical (see also the action catalogue for energy reduction in tunnels, which the COB published on 8 December 2016). The government, provinces and cities have formulated solid ambitions. The fact that road tunnels are 'energy guzzlers' means that a relatively high energy reduction is possible. The **Ministry of Infrastructure and the Environment** already noted in 2014 that an increase in energy consumption for infrastructure since 2012 has been due to tunnels and it will continue to increase until 2020. Of the total energy consumption for Rijkswaterstaat's primary processes, tunnels are already responsible for 16% (22.7 GWh/year). With the construction of several new tunnels, that share will increase further in the coming years.

Chapter 3 - A central role for adaptivity

What characterizes the outlined developments is that they evolve fast and are associated many uncertainties. We find ourselves in situations when no sooner a choice has been made than new accelerations or delays of the developments emerge with new alternatives that are better or cheaper or require a different approach to the chosen solution. Even a 10-year period (which is shorter than the current turnaround time of a tunnel project) is long when it comes to estimating the impact of, for example, the use of big data, the energy transition or self-driving vehicles. In such a world, a vision still has a role to play, but the choices will primarily be driven by actual practice. It is then important not to just consider the optimisation of the existing infrastructure but to also be open to new and unexpected solutions. Thinking in terms of changes and adaptations – adaptive thinking – must therefore become part of our DNA.

3.1 Uncertain future

Adaptive thinking is primarily suitable to dealing with uncertain long-term developments. For example, the **Delta Programme** – which must take an unknown sea level rise into account – is based on an adaptive approach. It is characterised by flexible, customisable measures that can be adjusted when the sea level rise is faster or slower than expected. This approach has been chosen based on the experience that the other option, the one based on robust (overdimensioned) measures – increasing the height of all dikes by another metre – may work in the medium but not in the long term. Robust measures are costly and the long-term uncertainty margin is so high that it is highly likely that the measures taken subsequently will prove not to be the right ones.

Pieter Bloemen, strategy and knowledge advisor in the Delta Programme Commissioner's team, recommends two things: ‘If there is no acute time pressure, take the time to reflect on a future vision and possible measures. And use an adaptive approach based on multiple possible future scenarios.’ He thinks the following four points are important in such an approach:

- In case of short-term decisions, take various plausible long-term tasks and the associated band widths into account.
- Consider various adaptation or development paths, and make sure that you can alternate between them quickly, if necessary: I know where I am now, I know more or less what is going to happen in the long run and I'll draw a clear picture of what to do in the short term. The starting point here is 'context first': under which circumstances should I intervene? Next, you will find out in which scenarios these circumstances are likely to occur.
- Ensure flexibility. Choose adaptation paths that offer room for interim adjustments.
- Open your agenda to others: linking, combining investment agendas. For example, combining tunnel construction with measures to improve the environment, nature, spatial quality.
- It is conceivable that changing factors can be anticipated without the need for structural or technical adjustments. Anticipating changing factors may also be part of changing the behaviour of road users, for example by adjusting the maximum speed or accessibility of tunnels for certain types of vehicles. This underlines the fact that adaptability cannot just be seen as an issue for the sector, the user must always be considered when discussing solutions.

The unpredictability and speed of developments mean that we must be adaptive (as a competence), organise adaptively (as a method) and pursue adaptive solutions/products (as a result). The latter means that the tunnel of the future is an adaptive tunnel, both in the process of creation and in the utilisation phase and at the end of its life.

3.2 Gaps in knowledge

Adaptive thinking is also necessary because there is still much that we do not yet know, for example, the actual lifespan of materials and structures, new fuels and new materials. Experts point out that we do not know the lifespan of concrete (underwater) and that the statement 'we build tunnels for a 100 years' is more based on assumptions than on research. Research into (fire) safety with regard to vehicles with other types of fuel (batteries, hydrogen) is still in its infancy.

Ron Beij of the Amsterdam-Amstelland fire brigade and the Knowledge Platform on Tunnel Safety (KPT) says the following: 'We do not really know where the developments concerning other types of fuel are heading. This complicates matters. Cars and buses running on hydrogen already create an additional risk, as safety systems will already be triggered at an ambient temperature of 110 degrees. In the event of a car fire in a tunnel, that temperature is soon reached and hydrogen gas can be released which will almost certainly ignite. In the case of vehicles using compressed natural gas, pressure relief valves are used for safety. The gas discharged through such a valve can catch fire and cause huge bursts of flames. This has already happened to a bus in Wassenaar. The problem is that vehicles approved by RDW for use on Dutch roads cannot be refused access to tunnels. For the transport of hazardous goods as cargo, the ADR ("Accord Européen relatif au transport international de marchandises Dangereuses par Route") applies. There is no separate legislation for the use of the same substances as vehicle fuel. So, there is still work to be done in that regard. We need to figure out how we can deal with this. First of all, we must collect all the international research already done in this area (including research by the International Fire Academy). The KPT can play a role in this. We currently do not yet know the hazardous properties well enough. That is a global problem.'

3.3 Need to grow (or shrink) with developments

If we think adaptively, we can ensure that there is maximum room for responding to new or changing circumstances, insights, expectations, and technical and social developments. Think of taking measures to adjust the quality and safety levels, prevent disturbances or reduce costs.

The tunnel's adaptability is not limited to (the material usage of) the tunnel including all installations, but also includes the multifunctional use of the tunnel and adaptability in time (difference day/night or winter/summer) depending on user needs.

Pieter Bloemen recommends tunnel managers to be flexible with their policies. As an example, he mentions the demands with regard to availability and (security) requirements. 'Look at which traffic links/transport axes are really essential and which are less important, and adjust facilities and investments accordingly. On less important routes, you can choose lower availability requirements because a temporary shutdown for maintenance, for example, has less effect.'

Paul Janssen, project director of the Rotterdamsebaan project, says, for example: 'Technical developments in the field of tunnel systems (TTI) and software are moving very fast. This means you cannot really design a tunnel that will be state-of-the-art when it is completed in five years' time. To be able to respond to these rapid developments, you have to leave some of the choices open for a long time and think carefully about when you choose a freeze moment. This also applies to safety. In the future, fewer safety facilities will be needed in tunnels as cars are increasingly equipped with more safety features.'

If we look at a tunnel as a system element, we will see new possibilities arise. Tunnels are becoming increasingly part of the system and the environment, but the tunnel itself does not determine the system and its environment. If we take the (wishes of the) environment as a starting point (from thinking in terms of objects to thinking in terms of systems), we need to think about whether the functions of tunnels should be the same at any time of the day and at any time of the year.

Carlo van de Weijer: 'The entire infrastructure, including tunnels, will need to become more flexible in its functions. You must be able to adjust the function to the demand of the moment. For example, you can park at the promenade in Domburg in winter, whereas in summer it is an exclusively pedestrian area. Rapid developments and space constraints lead to longer-term flexibility. There will always be something we cannot yet predict. That creates the demand for implicit flexibility. A 30-year traffic plan does not fit into that anymore. What you're looking for is a tunnel without a fixed plan and no frills. The changing functions and value of tunnels mean that organisations must become more flexible. The adaptive capacity of the sector is being put to the test. Adaptive working has consequences for tunnel professionals, the organisation, alignment with and policy development in government, legislation and financing and contractual forms, so tunnels can be easily customisable, such as a tidal flow on the motorway.'

Erik Vinke, integrated projects specialist at Vialis, says about adaptability: 'With an adaptive tunnel, you must think of a standard tunnel integrated in a flexible environment. This means that the tunnel should be a kind of puzzle piece that can be integrated into any environment. Demands are made for the link to the environment, but the tunnel does not determine what the environment will look like. The National Tunnel Standard helps with the tunnel systems, but the civil design and construction methods do not take that sufficiently into account yet. For example, when designing from a long-term vision, there must be ample room for adjustments in pipework, cabling and installations. For a long-term vision, one can also take into account the potential for changing use, such as a railway tunnel that becomes a road tunnel or vice versa, or the multifunctional use of tunnels through combinations with other underground functions such as parking, distribution or data centres.'

Independent consultant Leo Leeuw finds that tunnels can indeed affect the extent to which the tunnel's environment is adaptable: 'A tunnel design imposes constraints on its environment. It is not possible to later build on or next to a tunnel. Considering future buildings on or next to a tunnel leads to additional design requirements based on assumptions and therefore cannot always be met in practice.' In particular with regard to river crossing tunnels, Leo Leeuw points to developments in shipping. Larger ships lead to a greater draught. For example, the required covering of the Kiltunnel in the Dordtse Kil means that that river cannot be dredged to the ideal depth for shipping. And the other way round, other, new wishes from the environment may necessitate adjustments to tunnels. For example, research has been carried out into the possibility of lowering the Benelux Tunnel to increase the accessibility of the Rotterdam city ports.

3.4 Adaptation to changing laws and regulations

The choice that the government makes to be able to anticipate better and faster in rapidly changing circumstances is an important development for tunnels. To achieve this, the government is working to increase the flexibility in decision-making and implementation processes. This process has been going on for some time and will have more and more impact. For infrastructure projects, the Environmental Planning Act, which, from its focus on flexibility and co-creation, imposes a different responsibility on the market, will have a major impact. On 20 September 2016, the Dutch Cabinet responded in a letter to the Lower House on the Interdepartmental Policy Research (IBO) 'Flexibility in Infrastructure Planning' (March 2016), which 'outlines policy options that, in the opinion of the Working Group, help to increase flexibility and ease the administrative pressure while retaining the benefits of longer term planning'. The key question of the report is: 'In what way can a more flexible programmatic approach (more focused on tasks instead of solutions) contribute to a more effective and efficient infrastructural planning and funding?'

The **Cabinet** states in the letter: 'In recent years, the Cabinet has implemented a transition of the MIRT (Multi-Year Plan for Infrastructure, Spatial Planning and Transport) with programmes such as "Better Benutten"("Better Use"), "Nieuwe Aanpak Bereikbaarheid" ("New Approach to Accessibility") and Updating the Multi-Year Plan for Infrastructure, Spatial Planning and Transport. Wide-ranging, area-targeted uptake and balancing of multiple tasks, such as accessibility, sustainability and economics, in close collaboration with the environment and tailor-made solutions, so that solutions other than infrastructure solutions will emerge. This sets the course for better responses to the current and future issues and developments. Such flexibility is needed because changes are becoming more rapid and less predictable. In addition, the Cabinet gained good experience in the Delta Fund with an adaptive approach based on the Delta Programme.' The government and the writers of the Interdepartmental Policy Research note that the current practice limits the flexibility needed to 'address new developments and tasks, such as technological innovations'.

The government wants 'to steer on broad spatial-economic tasks in accessibility tasks in the exploration phase and exercise less control on concrete projects. This creates room to investigate solution directions and to make final decisions on solutions. What we now know (almost) for certain, we can do now. What we do not yet know (well enough), we will keep open, and, if necessary, we will agree as to when we will be able to decide. When there is a lot of uncertainty, we will work more and more within adaptive programmes, including for accessibility, to stay flexible and to be able to respond well to developments.'

In particular, in view of wide area tasks in urban areas, the Cabinet 'no longer wants situations in which the exploration focuses solely on one solution or modality that play the central role at the start of the exploration and on which the reservation of resources is based. To this end, the principle of a 100% view on funding at the start of the exploration will also be changed to 75%. This aims to introduce a stimulus to creatively search for the best and most effective package of solutions, and to seek co-financing.' The Cabinet also wants 'to keep room in the budgets, keeping a part of the budget available allows us to respond to current and unforeseen issues and developments and to take short-term measures in anticipation of possible long-term investments'.

The **PBL Netherlands Environmental Assessment Agency** arrives at the same conclusion. In the 'Exploration of Environmental Tasks for the National Environmental Vision', the PBL states: 'Adaptive policy allows the government to take into account external uncertainties (PBL 2011a; PBL 2011b; CPB & PBL 2015). Adaptive planning is a strategy whereby investments are made for the shortest possible future or in such a way that adjustments can be made at low cost. It is then considered whether, in view of the latest developments, the planned follow-up investments are still necessary. Large risky investment projects are cut into sections, which, if necessary, will be executed in stages or cancelled if the forecasts fall short (PBL 2011b). With adaptive policies, it is important to continuously keep track of developments, to be able to adjust policies in a timely fashion and to decide whether to invest or not. Monitoring developments in order to adjust policy in a timely manner is an important part of the knowledge agenda. For example, the need for adaptive policies arises during new urbanisation projects and the construction of infrastructure.'

3.5 Retention as vital objects

It has not yet crystallised where exactly adaptivity begins and ends. Change is constant, but we assume that tunnels will always remain vital objects within the infrastructure, that the number of tunnels will grow and that the construction, management and maintenance will continue to focus on safety, availability and quality of life. **Johan Bosch**, safety officer of road tunnels at Rijkswaterstaat said during a meeting of the COB Platform on Safety: 'Adaptivity is a beautiful starting point in uncertain times, but it does clash with the fact that a tunnel is an underground object in concrete. We need to make sure we agree on where we are looking for adaptivity. We will not suddenly change the track width. We have also been able to find solutions in a flexible way to the increasing width of cars over the past decades.' Dr **Albert Manenschijn**, head of tunnels and wet civil engineering works at Rijkswaterstaat: 'The next step is to find out how to make something that was moulded in concrete in the past more adaptive in a renovation.'

The impact of developments and hence the need for adaptivity is expected to be largely visible in installations and less in civil engineering. Standardisation contributes to smart and effective adaptability and will continue to do so in the future. As long as standardisation does not lead to uniformisation, standardisation will not act as a brake on innovation.

Chapter 4 - What does the tunnel of the future look like and how do we get there?

We already stated in Chapter 1: the future of the sector, now just a dot on the horizon, must mobilize us and give us a common objective. Based on the path so far, we have formulated this distant prospect as a future vision of the tunnel of 2050:

> *The tunnel of the future is a smart object constituting one whole with its environment, the city and the traffic network. It is built and renovated without causing disturbances and provides maximum availability during its lifetime. The tunnel adds value above and below ground, promotes flow, is safe and is valued in its form and function by users, owners, citizens and other stakeholders. Decisions are based on a balance of four factors – functionality, safety, availability and quality of life. Tunnels contribute to a climate-neutral and circular Netherlands. The COB network has adaptive and integral thinking in its genes and allows room for new technical and social developments.*