Appendix 4 – Safety in the Fehmarnbelt tunnel

This brief concerns three themes related to safety in a Fehmarnbelt tunnel.

Firstly, the general safety concept underlying the design of a Fehmarnbelt tunnel will be explained. This will then be elaborated on in relation to the three main types of events in a tunnel which involve safety risks: Accidents, fire and terrorist attacks. And in conclusion, the Mont Blanc tunnel disaster will be explained and the risk of anything similar occurring in a Fehmarnbelt tunnel. A detailed description of the Fehmarnbelt's tunnel ventilation system has been drawn up (appendix 2).

This brief does not deal with details of the structure of the emergency preparedness for a future Fehmarnbelt link, since this must be determined based on close dialogue with all relevant authorities on the Danish and German sides of the link, which have not yet been concluded. The dialogue with the emergency management authorities has its starting point in an account of the legal basis for Danish and German authorities' safety and emergency work, which Femern A/S has prepared, with a view to determining the organisational frameworks for a Danish-German emergency preparedness cooperation on the fixed link as well as the proposal for the emergency preparedness concept for a bridge and tunnel, which has been drawn up as part of the preparation of the technical design. Discussions with the emergency management authorities in Denmark and Germany commenced in November 2010 and the intention is to partly determine the organisational frameworks over the course of the next 6-9 months and partly, to obtain the emergency management authorities' views regarding the technical aspects of the safety and emergency concept for both bridge and tunnel.

General safety concept

The overall objective for the Fehmarnbelt tunnel is that it must be at least as safe when driving through the tunnel as when driving on a motorway in the open countryside.

To ensure this, the planning of the Fehmarnbelt tunnel constructions and all installations, etc. is based on an overall safety concept with the following safety prioritisations:

- *Accidents must be prevented*
  The primary goal is to achieve a design which prevents accidents and other emergency situations.

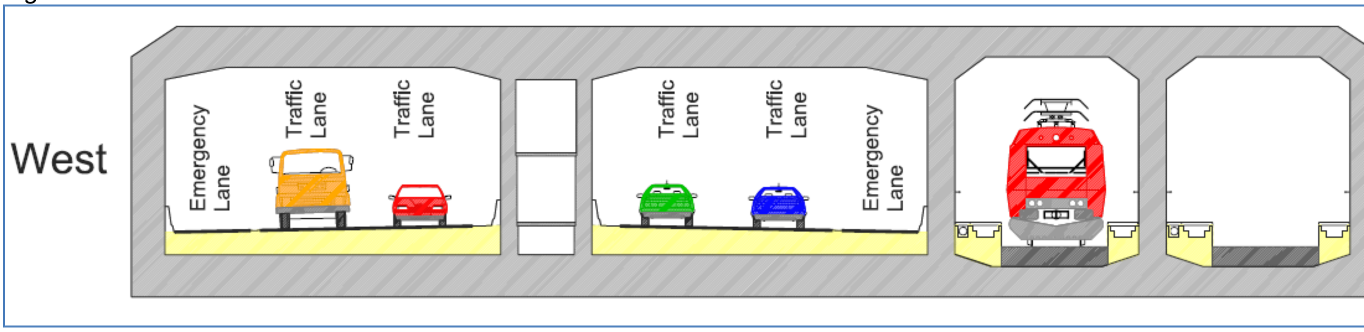
- *The consequence of accidents and emergency situations must be minimised*
  The secondary goal is to minimise the consequences of accidents and emergency situations if they cannot be averted.

- *The tunnel design must support the emergency preparedness work*
  The third goal is to provide sufficient safety systems and emergency preparedness procedures to ensure that the rescue services can deal with accidents and emergency situations with a high degree of safety.

The following describes the most important measures that have been decided on for each of the three priorities. A more detailed overview of the initiatives is presented in annex A.

To prevent accidents, a number of initiatives will be implemented. Initially, both the road and railway traffic will be unidirectional in the individual tunnel segments, which eliminates the risk of head-on collisions (see figure 1). Then there is the tunnel's road section – in contrast to the Øresund Link tunnel section – which has been designed with full emergency lanes meaning that the risk of having to cordon off a lane, e.g. in the event of minor accidents, etc. is significantly reduced, just as it will be possible, to a far greater extent, to carry out maintenance work without having to affect traffic areas or close the tunnel segment. The tunnel will also be equipped with a completely updated traffic monitoring and traffic control system, which among other things, makes it possible to quickly provide information to road users via variable signage, etc. just as speed limits will be able to be used to counteract congestion.

Figure 1: Cross-section of the Fehmarnbelt tunnel



To minimise the consequences of accidents, the tunnel is designed with four parallel tunnel segments and a central gallery, to ensure that refuge can always be found in the event of an accident or fire. The access doors between the tunnel segments are located every 100 metres and are clearly marked. The gallery is also equipped with excess pressure, which means that any smoke will not penetrate the gallery. Moreover, the tunnel is equipped with a fire extinguishing system (sprinkler system) and fire alarms, just as there are public address systems so information can be quickly provided to persons in distress.

To support the emergency work, the tunnel is equipped with fire hydrants every 50 m. There are facilities to manage and carry out rescue operations at both ends of the tunnel and detailed plans are being prepared for fire and rescue operation for various accident scenarios.

On the basis of the detailed tunnel design, risk analyses have been conducted which estimate how often accidents will occur with fatal outcomes in a tunnel and on a bridge. The results show that the risk of fatal accidents in a Fehmarnbelt tunnel is lower than on ordinary motorway and railway stretches.

Safety problems

The most significant safety problems in regard to a tunnel link will be normal traffic accidents, fire and terrorist attack.

Accidents

The road tunnel is designed and has the status of a stretch of standard motorway. Traffic accidents will occur as on any other motorway – however, typically with less frequency and fewer fatalities. Since the tunnel is designed as a motorway with full emergency lanes, the handling of an accident does not differ significantly from the situation on a standard motorway and general traffic accidents will not constitute a threat to the tunnel construction itself.

The same applies to the railway tunnel, where the same or an enhanced safety level will be achieved in comparison to the Øresund link.

Fire

The most probable causes of fire in the tunnel are traffic accidents as well as spontaneous fires in vehicles. The latter constitutes the largest percentage risk since only a negligible proportion of traffic accidents lead to fire.

In regard to the fire statistics, it is useful to place the risk in an overall context. Since the Second World War, approximately 150 persons around the world have been killed by fire in road tunnels. Of these, the fire in the Mont Blanc tunnel in 1999 accounts for only 39 deaths. A considerable proportion of the 150 persons were killed in a traffic accident which caused the fire and not as a result of the fire itself (with the Mont Blanc fire as an exception).

Given the large number of vehicles which drive through tunnels on a daily basis worldwide, there is thus an extremely small risk of death as a result of fire. This is also borne out by the statistics from the Øresund link where since the opening in 2000, there has been just one fire in a vehicle in the tunnel, which was put out by a hand-held fire extinguisher. This must be seen in the light of the fact that more than 50 million vehicles have crossed the link since its opening.

In the event that a fire occurred in a Fehmarnbelt tunnel, the risk that it would lead to serious damage to the tunnel is very limited. The tunnel is designed to be able to withstand a fire with temperatures in excess of 1,200 degrees for up to 3 hours without damage to the bearing elements. This corresponds to the temperatures that would occur as a result of a fire in an oil or petrol tanker.

In addition, the tunnel is equipped with sprinkler systems, fire hydrants, ventilation system, etc., which will limit the scale of the fire and ease the fire fighting considerably.

Terrorist attack

During the preparation of the tunnel design, the project has been assessed overall by an expert in international terrorism.

The conclusion is that the link on the one side might represent a tempting target for terrorists because of its size and the fact that it links two countries. On the other hand, the international terrorism strategy is believed to be moving in other directions, namely either against iconic structures (World Trade Center in New York, the Eiffel Tower, etc.) or against targets where there is a certainty that many people will be killed by a single strike (e.g. railway stations and metro stations).

The Fehmarnbelt tunnel, however, comprises none of these criteria. However, it cannot be completely excluded that a fixed link across Femern Belt could be exposed to a terrorist attack.

If a terrorist attack should occur against a Fehmarnbelt tunnel, the assessment is that the obvious form would be a bomb explosion. The consequences of such a bomb explosion would – if the bomb is powerful enough – have catastrophic consequences for persons who are in the tunnel at the time of explosion and for the tunnel itself.

However, a considerable blast effect would be required for the tunnel’s construction to be damaged. The tunnel’s outer walls are designed with 1.1 – 1.3 m steel reinforced concrete, similar to a bunker construction. Therefore, large amounts of explosives would have to be used to severely damage the tunnel. But obviously, even minor bomb explosions would result in personal injury.

Even though a Fehmarnbelt tunnel might be at risk from terrorist attack, it is improbable that the construction of a Fehmarnbelt tunnel would lead to an increased risk of serious terrorist attack in Denmark. There are already a number of obvious traffic-related terrorist targets in Denmark, which organised terrorists could attack (e.g. the Øresund link, the Great Belt link, Nørreport station, the Metro, etc.), so the fact that yet another terrorist target may be added to the list must, in principle, only be expected to affect the choice of target and not the overall risk of a terrorist attack.

The disaster in the Mont Blanc tunnel

In Central Europe, much of recent years' debate regarding safety in tunnels has been based on three significant fires that occurred within a short space of time: Mont Blanc (1999), Tauern (1999) and Gotthard (2001). Common to the three fires was that they occurred in tunnels with bidirectional traffic and both the sequence of events and consequences are precisely linked together with this fact. The Mont Blanc fire, in particular, received tremendous attention as a result of the high death toll.

The Mont Blanc tunnel is 11.6 km long tunnel between Italy and France, which comprises a single tunnel with two traffic lanes with opposing traffic, see figure 2.

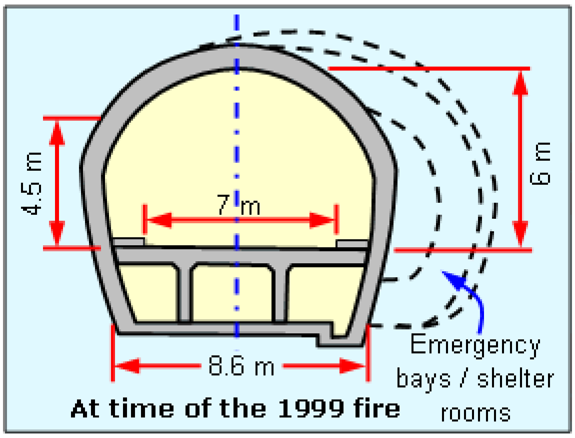


Figure 2 Cross-section of Mont Blanc tunnel

The Mont Blanc disaster occurred on 26 March 1999 when a fire from unknown causes ignited in a truck loaded with flour and margarine. When the driver discovered the fire and stopped the vehicle, it was about halfway through the tunnel. The driver tried unsuccessfully to extinguish the fire, which then advanced quickly and ignited the vehicles behind.

Due to erroneous operation of the ventilation system, among other things, the smoke drifted towards the French portal at great speed. The motorists who were caught behind the burning truck were thus shrouded in smoke and a large number of them died as a result of smoke inhalation and the effects of the heat. Vehicles located between the truck and the Italian portal were able to escape because of the relatively smoke-free conditions.

A total of 39 people died in the disaster, some of whom were rescue workers.

A similar incident of fire in a truck would not have the same disastrous consequences if it occurred in a Fehmarnbelt tunnel. Firstly, this is because the Fehmarnbelt tunnel (see figure 3 below) is designed with four parallel tunnels and a gallery, which means that evacuation of the tunnel would take place by distressed persons moving to another tunnel and thus away from the danger zone. The separated tunnels also mean that rescue personnel would be able to move safely in the parallel tunnel all the way to the accident site, making it easier to fight the fire. Additionally, the Fehmarnbelt tunnel, as mentioned, would be equipped with sprinkler systems and a far better ventilation system, which would partly make it possible to cool/fight the fire and partly, make it possible to control the smoke. Subsequently, in terms of preparedness, the Mont Blanc disaster, among others, has been learned from, which has resulted in far better regulation at the European level which determines requirements for emergency preparedness planning.

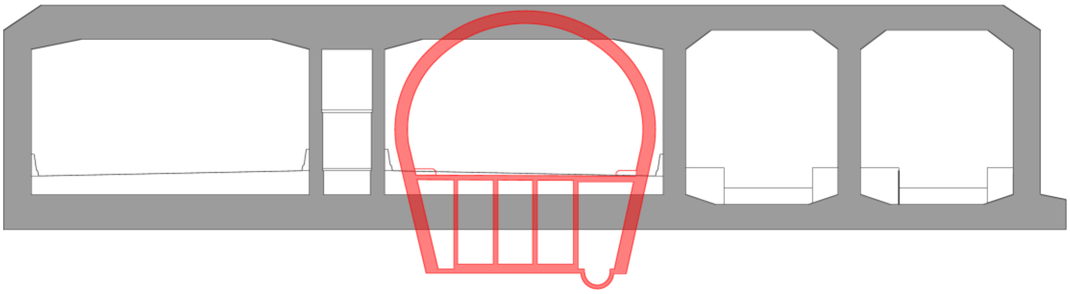


Figure 3 The Fehmarnbelt tunnel's cross-section compared to the Mont Blanc tunnel

Below is a further, brief comparison of the conditions in the Mont Blanc tunnel in 1999 and the existing project for the Fehmarnbelt tunnel.

Mont Blanc	**Fehmarnbelt**
The only escape option was booths with limited resistance to smoke and heat.	Option for escape to central gallery with positive pressure as well as neighbouring tunnels
Responsibility for tunnel operation shared between France and Italy	Tunnel operation as well as management of fire and rescue work is unequivocally in one place (Denmark).
The relevant extinguishing material was located on the French side - but it was only possible to penetrate from the Italian side	Separated tunnels, i.e. fire fighting vehicles can come through from both ends in the unaffected tunnel. Additionally, suitable fire and rescue vehicles are required to be located at both sides of the belt.
No fire extinguishing system	Sprinkler systems will be installed
No automatic incident detection	AID (Automatic Incident Detection) system will be installed
Ventilation system was incorrectly operated (exhaust system was used for injection)	Simple ventilation principle with automatic start-up – few possibilities of incorrect operation

Appendix A – Detailed information

As part of the work of designing a proposal for a tunnel solution for a fixed Fehmarnbelt link, comprehensive material has been prepared, which deals with various safety issues, including for example, the following documents which underlie this brief:

- *Operational Risk Analysis* – This report describes the individual risk contributions so that the combined safety level is documented and complied with for the developed tunnel project

- *Safety & Rescue Plan* – This report describes the various safety systems ahead of the safety concept and the future safety plan

- *Safety concept* – is a detailed review of the three levels into which the tunnel safety is divided: Prevention, self-help and the rescue work

Overview of risk minimising initiatives in the Fehmarnbelt tunnel

As stated, the Fehmarnbelt tunnel is designed based on an overall safety concept and based on the following three priorities:

- *Accidents must be prevented*
- *The consequence of accidents and emergency situations must be minimised*
- *The tunnel design must support the emergency preparedness work*

The following lists the most significant design elements, which support the three priorities.

Prevention of accidents

The following measures in the tunnel contribute to preventing accidents, among other things:

- Tunnels have unidirectional traffic – no possibility of head-on collisions
- Each tunnel is supplied with an emergency lane – as on a standard motorway
- Slight incline/drop of the traffic lane
- Extensive and up-to-date monitoring, control and communication systems provide fast and precise information on any incidents
- Constantly manned control centre
- Traffic control system which prevents congestion
- Variable signage with the possibility of giving information to road users
- Height detection at entrance portal
- Varied lighting of the tunnel to prevent driver fatigue
- Active road marking lights along the lane

- Maintenance activities can largely be performed outside of the traffic area

Minimising of consequences

The following measures contribute to minimising the consequences of accidents in the tunnel:

- Four parallel tunnels + central gallery – which will always be a safe place to take refuge
- Cross connection between tunnels every 100 m
- Excess pressure ventilation of central gallery – ensures fresh air and no smoke
- Significant fire resistance abilities of critical load-bearing elements. (The tunnel is designed for a regular fire lasting 3 hours, which means that there are no or only insignificant damages to the load-bearing structures in this period)
- Automatic fire detection
- Fire extinguishing system (sprinkler system) in all tunnels
- Longitudinal ventilation system with large capacity
- Public address system provides the possibility of instructing road users
- Transmission of instructions to road users via car radio on FM bandwidth
- Clear marking of emergency exits - with signs showing the distance to the nearest exit
- Emergency lighting that comes into operation in the event of a power failure
- Emergency stations with, among other things, emergency telephones and fire extinguishers every 50 m

Support of rescue work

In those instances where rescue work is required, the following measures support the emergency management authorities' work:

- Range of communication systems: FM radio, mobile telephony, emergency telephones, TETRA radio system
- Fire hydrants located every 50 m in all tunnel sections
- Link between the various tunnel sections every 100 m
- Facilities at both tunnel portals for management and execution of rescue work
- Automatic fire extinguishing system (sprinkler systems) in tunnel sections – facilitating any rescue work
- Detailed plan for fire and rescue work for various accident scenarios

Annex B - Ventilation system of the Fehmarnbelt tunnel

1. Introduction

Based on input from the company’s tunnel consultants, Rambøll, Arup and TEC, a short description is provided in this brief of the ventilation system in the Fehmarnbelt tunnel, including a description of the differences from the ventilation system that was proposed in the 1999 feasibility study.

The ventilation system has two purposes:

In daily operation: If natural ventilation (i.e. the piston effect from vehicles) is not sufficient to comply with the set air quality requirements, the ventilation system will ensure the necessary supply of fresh air.

In the event of an accident: In the rare event that a serious fire or discharge of harmful gasses occurs in the tunnel, the ventilation system will ensure that smoke or gasses are vented out of the tunnel so that those persons who are in the tunnel are not harmed.

In the Fehmarnbelt tunnel, a so-called longitudinal ventilation principle is used where the ventilators inject air through the entire tunnel from the entrance portal to the exit portal (see the figure below). The system in the Fehmarnbelt tunnel comprises groups of so-called impulse ventilators (typically three), which are located in the ceiling of the tunnel about every 400 m.

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Longitudinal ventilation with impulse ventilators

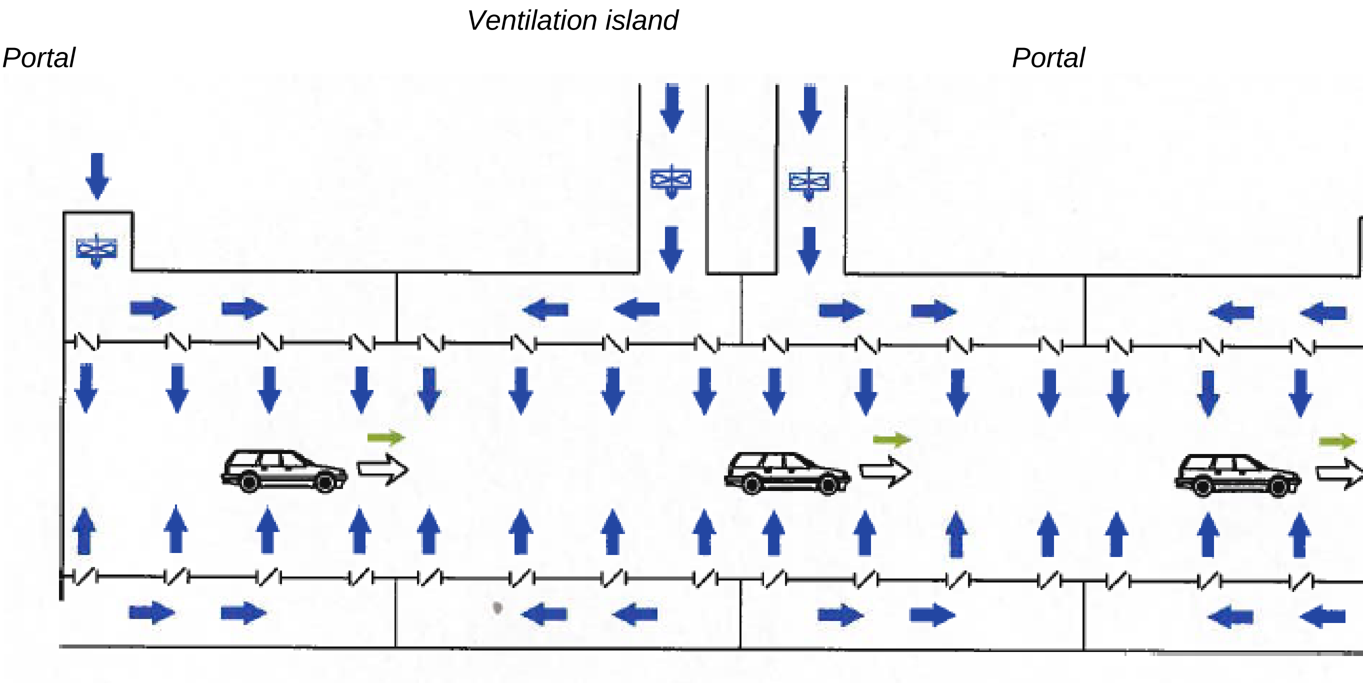
2. Daily operation of the ventilation system

In daily operation, the piston effect from vehicles will normally provide sufficient air exchange in the tunnels. However, situations might arise in which vehicle speed is reduced because of maintenance work or an accident. In such instances, it would be necessary to start the ventilators in order to comply with the recognised permissible values for pollution of the tunnel air.

The pollution concentrations would increase evenly through the tunnel and would reach maximum levels just before the exit portal. The capacity of the ventilators must thus be sufficient so that the permissible values are complied with here.

In the 1999 feasibility study, it was concluded that it was not operationally economic to install the ventilation system with purely longitudinal ventilation, since the necessary capacity would be unrealistically large and the necessary working time would be high.

Therefore, the feasibility study operated with another concept for ventilation, namely so-called semi cross-ventilation – see the figure below.



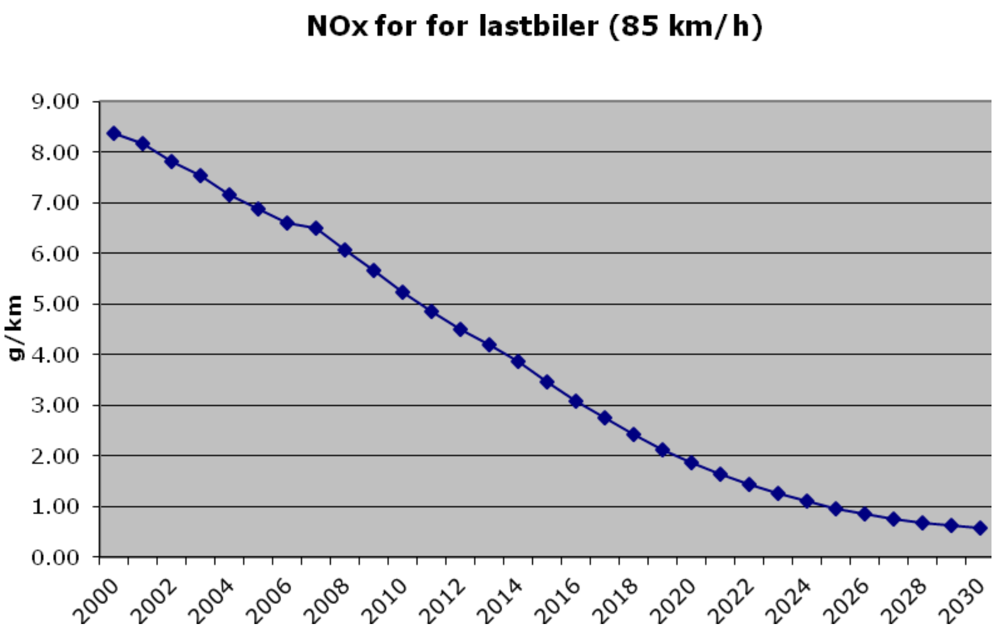
Semi cross-ventilation system used in the feasibility study

The feasibility study included a ventilation island in the middle of Fehmarnbelt, which is used for the intake and discharge of ventilation air. The air is injected into the tunnel through a longitudinal channel, which is supplied partly from the ventilation island and partly from the ventilation buildings at each portal. Some of the air is drawn in via the ventilation island and the remainder leaves the tunnel through the portals.

With this ventilation concept, significantly more air can be supplied to the tunnel than with purely longitudinal ventilation, but the principle also entails a need for many electromechanical components which must be maintained and entail greater risk of component failure. It is noted that the ventilation concept in the feasibility study did not provide the possibility of controlling the spreading direction of smoke, which would be a requirement today.

At that time when a semi cross-ventilation system was assessed as the optimal system, the reason was that in the feasibility study, emissions from vehicle exhausts were used which were far higher than the values expected today. Emission data in the feasibility study originates from the early 1990's. In the past years up to today, massive reductions have occurred in emissions from vehicle exhausts as a result of technical development and more stringent environmental requirements.

This trend is expected to continue over the next decades towards very low emission values – see the diagram below which indicates the expected trend in NO_x emissions from trucks.



The drop in emission values more than outweighs the forecasted increase in traffic volume.

The dramatic drop in emissions has made it possible to use purely longitudinal ventilation in the Fehmarnbelt tunnel, which makes the ventilation system simpler and more robust. Moreover, a reduction of the combined construction costs is achieved given that the size of the tunnel cross-section can be significantly reduced.

3. Ventilation during a fire/accident

In the event of fire or discharge of toxic fumes the ventilation system must ensure that road users can get safely out of the tunnel and that the rescue and emergency teams can work safely.

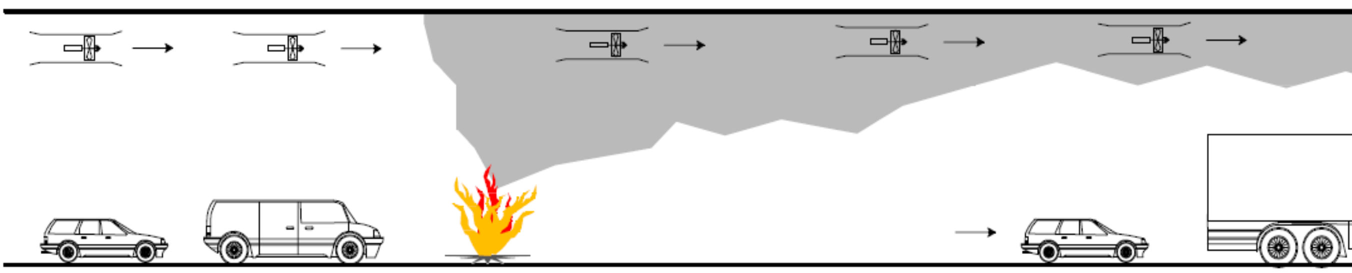
This will take place by controlling the spreading direction of smoke or gasses – possibly supplemented with an exhaust system that can remove smoke or gasses entirely or partially. The exhaust system is relevant in those situations in which vehicles that are in the downdraught of the fire cannot for one reason or another drive freely out of the tunnel.

This situation can occur in tunnels in urban areas where traffic signals, etc. can create queues which can propagate back into the tunnel. However, the Fehmarnbelt tunnel is a motorway tunnel in a rural district where, under normal circumstances, the traffic flows freely – supported by an intelligent traffic control system.

Only if a fire in the tunnel occurs simultaneously with another accident downwind of the fire, would a situation arise in which a number of vehicles would be prevented from driving freely out of the tunnel.

The statistics in Denmark as well as in other countries show, however, that such a double event is extremely rare. Should it nevertheless happen, the road users in the vehicles who are prevented from driving on after accident number two, would be asked via the various communication systems (public address system and radio transmission) to leave their vehicles immediately and go to the nearest emergency exit. There will be maximum 50 m to the nearest emergency exit, which means that the evacuation time would be quite short.

The longitudinal ventilation system in the Fehmarnbelt tunnel is used to force smoke or gasses in the direction of the traffic (see the figure below).



The road users who are on the stretch between the fire and the exit portal proceed unhindered out of the tunnel. The ventilators ensure that the tunnel section upwind from the fire is kept free of smoke for those road users who remain blocked by the fire so they can safely leave their vehicles and seek safety in the central gallery.

Additionally, a sprinkler system is installed in the tunnels, which will contribute to limiting the size and spreading of a fire locally and thus also smoke production.

The ventilation concept in the feasibility study utilised the channel system, which had been planned in consideration of ventilation during daily operation (see section 2). One of the longitudinal channels for injection of air was thus used for exhaust instead by turning the air direction.

This concept is not recommended today since it has been found that it takes too long to turn the air direction in such large channel systems as is the case here.

The ventilation concept in the feasibility study did not, as previously mentioned, provide the possibility to control the spreading direction of smoke. This would be a requirement today and it would mean that the originally described ventilation concept would in any case have to be supplemented with impulse ventilators for longitudinal ventilation.

The existing safety concept is thus dimensioned to control and extinguish a significantly larger fire event than was the case for the feasibility study and thus also fulfils the requirements in the German guidelines.