Hyperloop in the Benelux: Opportunities for cross-border connectivity and high-tech cluster development

Goudappel ABEL

Hyperloop in the Benelux: Opportunities for cross-border connectivity and high-tech cluster development

Status:
Final Report

Goudappel
Anna van Buerenplein 42
2595 DA Den Haag
The Netherlands
+31(0) 570 66 62 22

info@goudappel.nl
www.goudappel.nl

RebelGroup
Wijnhaven 23
3011 WH Rotterdam
The Netherlands
+31 10 275 59 95

info@rebelgroup.com
www.rebelgroup.com

Table of Contents

Overview of tables

Overview of figures

Executive Summary

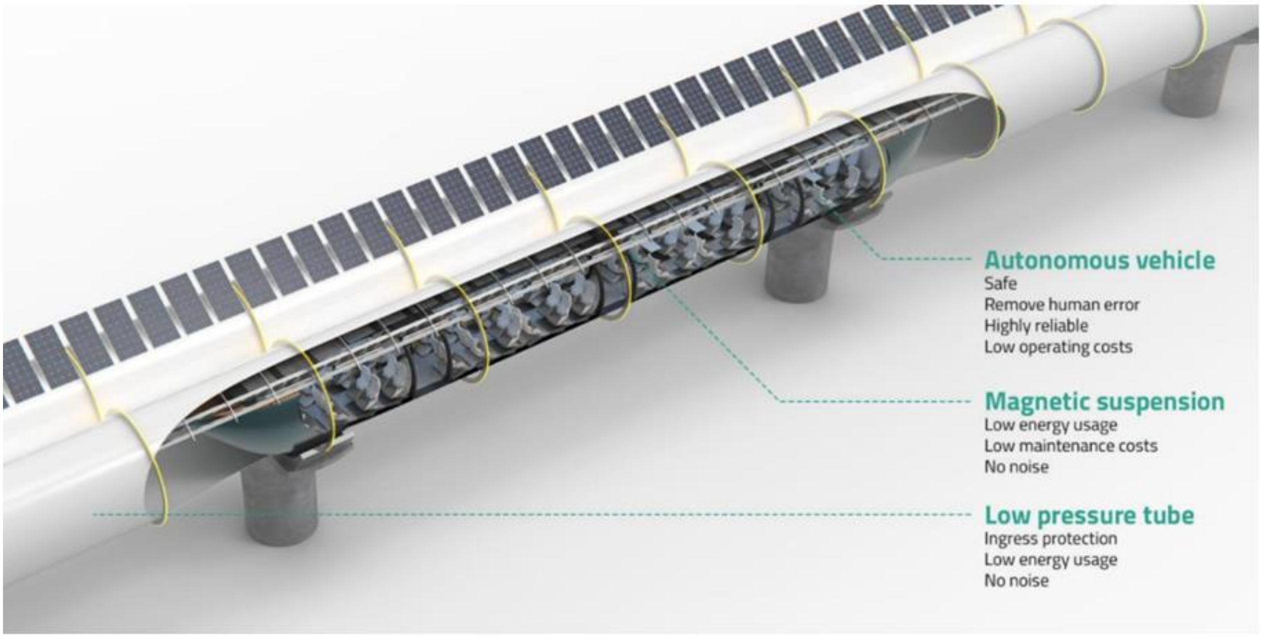
This study concerns the potential of Hyperloop development for the Benelux countries and North Rhine-Westphalia.

The study has two main components:

1. Cluster opportunities: a description of the opportunities and considerations for the development of a high-tech industrial cluster with companies and governments from the Benelux and North Rhine-Westphalia around the Hyperloop and related technology.
2. Proof-of-concept: research into opportunities for a first Hyperloop line of several kilometres in Benelux and North Rhine-Westphalia, with specific attention to cross-border links and for both freight and passenger transport modalities.

The study was commissioned by the Ministry of Infrastructure and Water Management of The Netherlands on behalf of the Hyperloop working group of the Benelux, in close cooperation from the German state of North Rhine-Westphalia (referred to jointly as Benelux-NRW).

Figure 1: Hyperloop concept



Source: Hyperloop Development Program, Hyperconnected Europe: a vision for the European Hyperloop network

This study is developed in the context of advancing development of Hyperloop technology, with more and more public and private stakeholders exploring its potential impact on transportation, spatial planning and economic opportunities.

In that light, the Benelux-NRW considers the potential strength of the member states and regions therein as an attractive location for Hyperloop development, based on several factors.

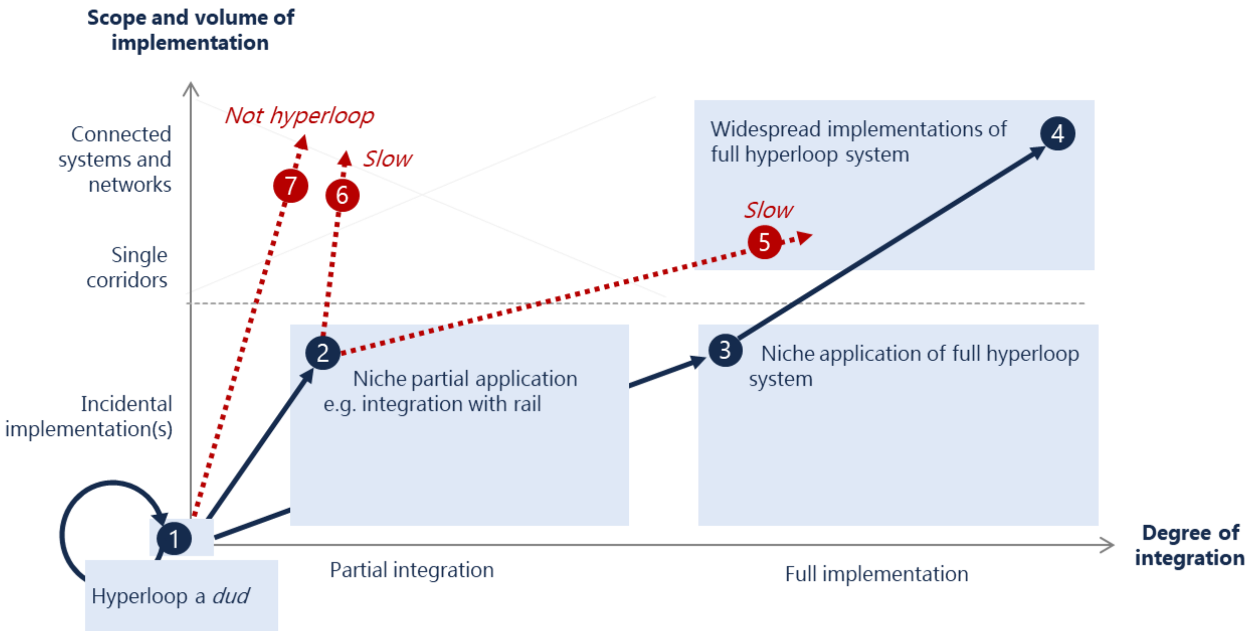
These factors include the presence of an active private ecosystem for Hyperloop technology innovations, substantial existing public sector involvement and interest, multiple forms of public-private cooperation such as the Hyperloop Development Programme to foster joint development efforts and investments, as well as a strong research and knowledge infrastructure and generally significant innovativeness of national economies. Furthermore, Hyperloop potentially offers the Benelux-NRW a more sustainable and more efficient form of cross-border connectivity benefiting both the region's key urban agglomerations as well as its more peripheral areas.

Possible Hyperloop Futures

To explore possible trends and directions of Hyperloop development as well as measures to be taken by Benelux-NRW governments to make the most of potential opportunities offered by Hyperloop, different possible futures for Hyperloop development are explored. This is done using a scenario approach.

The scenario approach is based on two main axes of uncertainty with regard to the future development of Hyperloop: the integrity or degree of integration of Hyperloop development, as well as the scope and volume of Hyperloop implementation. *In what form* will Hyperloop be built and used, and *how much* of it will eventually be built and used?

Figure 2: Scenario development on identified uncertainty axes



Source: Consultant

As illustrated above, four plausible scenarios resulting from this approach are considered:

1. No progress scenario: Hyperloop development does not progress beyond small- to real life testing and proof-of-concept systems.
2. Niche application of integration with rail: one or a limited number of corridors are developed and/or retrofitted with partial Hyperloop implementations (e.g. integration with rail through pod-block operations, maglev, etc.).
3. Niche integral implementations: one or eventually a limited number of transport corridors see full connection Hyperloop implementation, but in the bigger scheme of things Hyperloop remains a 'niche' phenomenon rather than a new universal modality.

4. Universal integral implementations: Hyperloop technology is implemented 'full concept' (high frequency service patterns, low pressure system, magnetic levitation and a linear motor) in a large number of corridors and networks within the EU and in other global regions.

Across these four plausible scenarios, public sector decisions concerning Hyperloop development including various government support measures and policies should result in sufficiently beneficial expected outcomes.

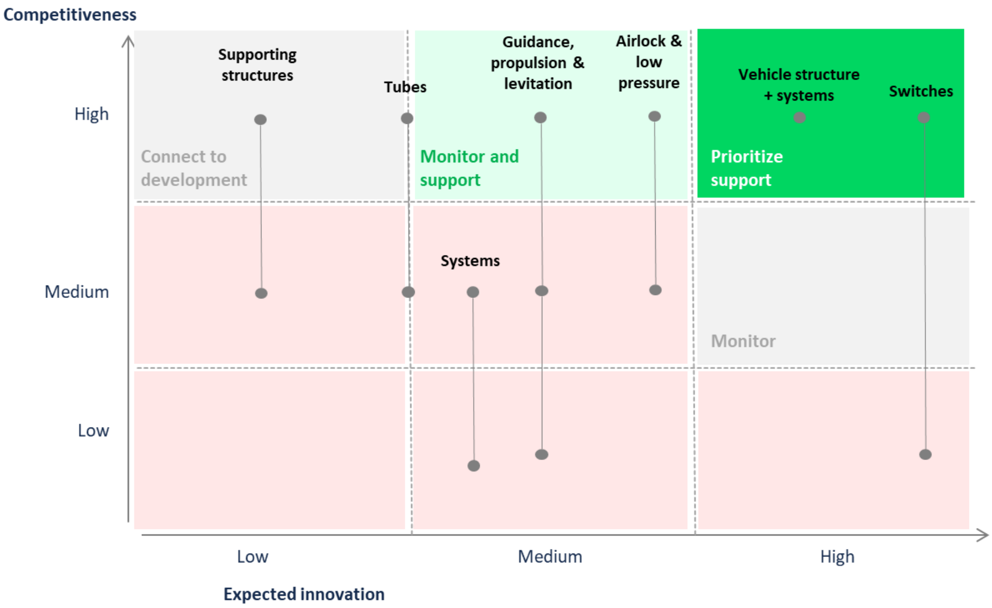
More generally, several conditioning factors determine progress from one scenario to the next. These include the need for demonstration of the viability of Hyperloop as a transportation technology, ways to achieve integration with existing infrastructure, the contribution of substantial public funding as private finance is unlikely to be sufficient to meet the necessary investment and operating needs of initially technology development and later a functioning Hyperloop system/network, and regional cooperation. Regional cooperation within Benelux or EU frameworks will facilitate access to EU funding sources.

Cluster Development

The study examines the opportunities for developing a Hyperloop-related industrial cluster in the Benelux-NRW region. Hyperloop systems consist of various subsystems, each with potential for innovation and competitiveness. The region has existing companies and capabilities that could form the basis of such a cluster. The analysis of potential Hyperloop clusters focuses on specific subsystems rather than the full Hyperloop system, as it is unlikely that the Benelux-NRW region will host a dominant integrator due to the required scale of production and the general tendency of integrators to (re)locate to the most voluminous markets.

For each Hyperloop subsystem, the expected level of innovation and the current competitiveness of the region are assessed. This suggests that the region has particular manufacturing strengths in areas like vehicle structure and systems, airlock and low pressure systems, and supporting infrastructure.

Figure 3: Indicative mapping of expected innovation and competitiveness



Source: Consultant

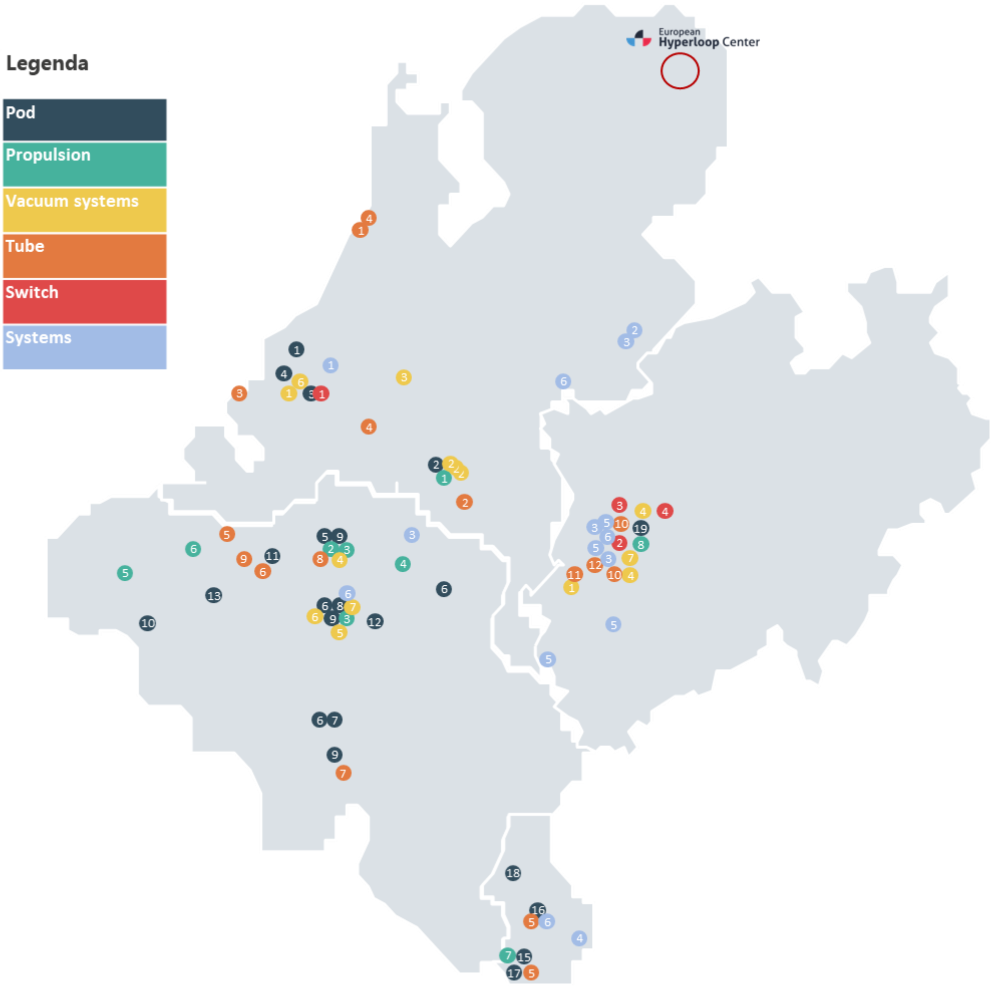
Possible public sector actions to support cluster development *especially with concern to* switches, vehicle/pod structure and related systems include:

- Facilitating collaboration, supporting R&D, and creating a favourable regulatory environment;
- Promoting exchange and spillover between academic and industrial researchers;
- Supporting supplier integration and development; and
- Nurturing technology developers to ensure they stay connected, protected, and ahead of the curve.

The current manufacturing capabilities align with the desire to develop the Hyperloop industry through an alliance between the Benelux + NRW governments, given that many of the current manufacturing sites are close to countries' borders.

The figure below illustrates an indicative list of manufacturing sites mapped per subsystem. However, no clear clusters emerge from this data. This lack of clustering may not be problematic, as travel times between these border regions are insignificant and do not necessarily impede cluster development

Figure 4: Indicative list of companies with manufacturing abilities



Source: Consultant

Possible Proof of Concept Connections

There are several potential corridors within which a first Hyperloop proof of concept connection in the Benelux-NRW region could be developed. Corridor identification is done on factors such as travel demand, freight volumes, and broad prosperity goals (economic growth, sustainability, accessibility, liveability, and innovation).

A multi-criteria analysis is used to shortlist the most promising corridors:

1. Amsterdam – Rotterdam - Antwerp – Brussels
2. Maastricht – Aachen – Liège

The analysis of transport potential is based on existing origin-destination data, which has limitations in accurately predicting the effects of a transformative new technology like Hyperloop.

The study highlights the need to develop more advanced multimodal models that can capture the significant changes in travel patterns and demand that Hyperloop might bring about.

Key challenges identified include data availability on cross-border travel, limited information on air travel, and the need to address first and last mile transport of goods to enable accurate projections of Hyperloop's transport potential.

Benelux-NRW Strategic Perspectives

Consolidating analyses and findings, the study outlines three strategic perspectives for governments with concern to Hyperloop development in the Benelux-NRW region:

1. *Drive for universal 'full' Hyperloop implementation*: Coordinated public-private effort to rapidly develop a comprehensive Hyperloop network.
2. *Facilitate gradual development, choose specialization*: Targeted public support for specific Hyperloop applications and cluster development.
3. *Let the market direct and decide*: Minimal public intervention, allowing the market to determine the pace and direction of Hyperloop development.

The choice of strategic perspective will depend on the region's priorities and the evolution of the Hyperloop technology and ecosystem.

The strategic perspectives are analysed in terms of the level of public sector inputs required, the potential cluster realization and connectivity outcomes under different Hyperloop development scenarios, and the overall economic value creation implications for the Benelux-NRW region.

The "drive for universal *full* Hyperloop implementation" approach involves substantial public commitment and funding, with the potential for significant economic value creation through innovation and productivity gains, as well as transport network decongestion.

The "facilitate gradual development, choose specialization" approach focuses on public support for partial Hyperloop implementations and the development of specialized capabilities, while the "let the market direct and decide" approach involves a more hands-off public role, with potentially lower economic value creation but also lower public investment risk.

Table 1: Approaches, scenarios and outcomes (summary of strategic perspectives)

Which approach for Benelux-NRW to take?	*Which sufficiently plausible scenarios may occur?*	*What level of inputs is associated with each approach?*	*What are likely cluster realization and connectivity outcomes for each approach, under different scenarios?*	
		Level of Benelux-NRW (funded) inputs implied	Benelux-NRW economic value creation implied	
			Cluster realization outcomes	Connectivity outcomes
Drive for universal 'full' Hyperloop implement-tation		◆◆◆◆◆◆		
	1- No progress scenario		●	-
	2- Niche partial implementations		●●	■■
	3- Niche integral implementations		●●●	■■■
	4- Universal integral implementations		●●●●●●	■■■
Facilitate gradual develop-ment, choose specialization		◆◆◆◆		
	1- No progress scenario		●	-
	2- Niche partial implementations		●●●	■
	3- Niche integral implementations		●●	■■
	4- Universal integral implementations		●●●●	■■■
Let the market direct and decide		◆◆		
	1- No progress scenario		-	-
	2- Niche partial implementations		●●	■
	3- Niche integral implementations		●	■■
	4- Universal integral implementations		●●	■■■

Source: Consultant

This analytical framework underlines that, in choosing a public support and investment approach, governments must decide whether they want to take more or less risk and correspondingly expect more or less net benefits.

The study concludes with a set of observations and limitations to keep in mind, emphasizing the need for public-private cooperation, the potential for replacing air traffic, the importance of developing advanced multimodal models, and the opportunities for Benelux-NRW to host early Hyperloop implementation and manufacturing activities.

1. Introduction

1.1 About this study

The development of Hyperloop technology is advancing, with more and more private and public stakeholders exploring its potential impact on transportation, spatial planning, and economic opportunities.

Private companies across the world are striving to develop Hyperloop technology into a safe, technically feasible, and attractive form of transportation. A shared short term goal for most is to create a working system with demonstration value, known as Proof-of-Concept (PoC), which can later be rolled out to a wider network of connections.

Meanwhile, public parties and public-private partnerships are increasingly working on broader issues such as regulation, standardization, network planning and integration, and the social value of Hyperloop.

In light of these developments this study was commissioned by the Hyperloop working group of the Benelux. There is also intensive cooperation with the German state of North Rhine-Westphalia on this topic, which is therefore included in the scope of this study and both are in most places in this study referred to jointly as Benelux-NRW.

The study rests on two legs:

- **Cluster opportunities:** a description of the opportunities and considerations for the development of a high-tech industrial cluster with companies and governments from the Benelux and North Rhine-Westphalia around the Hyperloop and related technology; and
- **Proof-of-concept:** research into opportunities for a first Hyperloop line of several kilometres in Benelux and North Rhine-Westphalia, preferably cross-border and for both freight and passenger transport.

After first describing these components separately, we will pay attention to the connection between both parts of the research by answering the following questions:

- What are the opportunities for a proof of concept connection and cluster formation in the Benelux and North Rhine-Westphalia?
- What does this mean for possible future prospects for Hyperloop development in our region, and what role do governments and the private sector play in this?

1.2 The Hyperloop promise

Hyperloop is a new modality consisting of pods traveling through near vacuum tubes

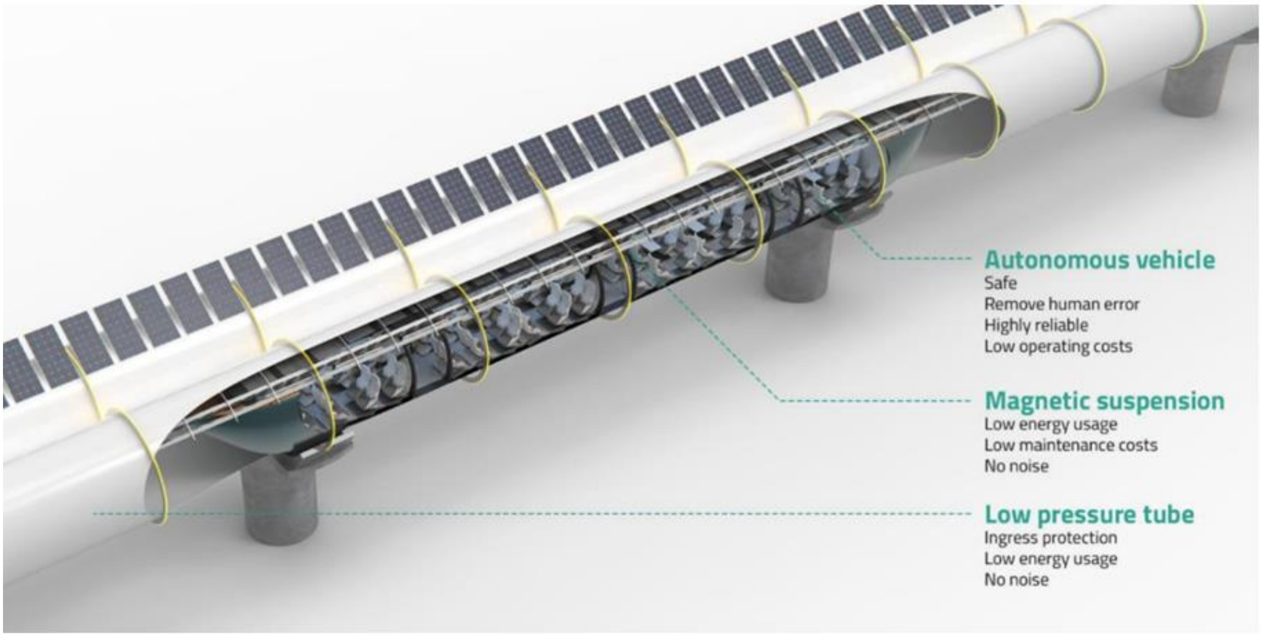
Hyperloop aims to revolutionize long-distance transportation by offering faster, more energy-, and environmentally friendly travel compared to traditional modes like cars, trains, or airplanes. The main technology the Hyperloop is a combination of three components

- **Pods:** Hyperloop transports persons and goods in autonomous pods which travel through tubes at high speed.

- **Magnetic suspension:** the pods are lifted from the track by using magnetic levitation that enable the pods to hover above the tracks.
- **Tubes:** the pods are propelled within tubes that provide a near-vacuum environment in which the pods are propelled by continuously reversing magnetic fields

The combination of these technologies enable the pods to move through the tubes at very high speeds. Estimates have indicated that speeds over 700 km/h could be achieved. However, many technologies and their integration need to be developed further. A visual representation of Hyperloop system can be found in the figure below.

Figure 5: Hyperloop concept

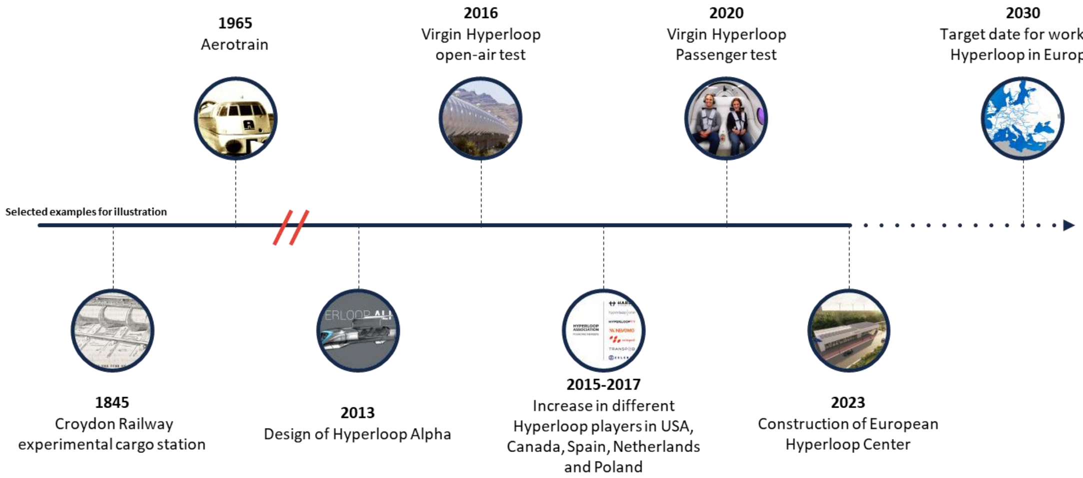


Source: Hyperloop Development Program, Hyperconnected Europe: a vision for the European Hyperloop network

- The ideas underlying the Hyperloop concept have been around for quite some time, some concept papers dating back to 1845. The development of the Hyperloop concept as it exists today was catalysed by the Hyperloop Alpha whitepaper. Following this, Elon Musk organized Hyperloop design competitions, which led to the emergence of several start-ups globally formed by participating student teams. Following this, Hyperloop One developed several studies showcasing the added value of the Hyperloop in 2016 and started testing the technology in their own test facility in 2017. Afterwards, more companies around the world started testing technologies at different centres.
- Even though the most important developments started in the United States, key players in Europe became more advanced in the years after, and several test facilities have sprung up throughout Europe. Afterwards, companies from Asia followed. The following pages present several of these companies and test centres.
- Across the board, in these test centres overall systems are reaching higher technology readiness (TRL) levels. For a working full scale proof of concept connection with actual transport capacity all TRL levels should be at 6 (out of 9). Several technologies already have this score. However, further developments are necessary before a working proof of concept connection can be developed.

The Hyperloop concept has been around for some time, but was reignited around 2013

Figure 6: Selected key moments in Hyperloop history



Source: : Railwaytechnology.com, Timeline: tracing the evolution of Hyperloop rail technology, Rebel & Goudappel analysis

- A project funded by the European Commission "Hyperloop Industrial Roadmap and pilots" is currently developing an industrial roadmap covering all the steps and milestones needed to the increase TRL levels to 9. In addition, the current state of technological development for all components of the Hyperloop concept is being mapped.
- An active ecosystem of public sector and large private sector 'corporate' stakeholders is closely monitoring the progress made. There is agreement that action from both types of stakeholders is needed, separately and jointly. The Hyperloop Development Programme is a good example of a public-private alliance to support cooperation and convergence of Hyperloop technology development.
- The Hyperloop Development Program (HDP) is an ecosystem that brings together companies and research institutes to collaborate on developing the hyperloop as a safe, energy-efficient, and commercially viable transport mode. The HDP aims to achieve several goals: proving the feasibility of hyperloop as a safe and sustainable low-emission transport mode for both people and goods, testing and demonstrating at the European Hyperloop Center that the technology functions as intended and can be operated safely, and identifying future prospects and opportunities for industries and stakeholders within the hyperloop ecosystem. These objectives are addressed through key aspects including safety, standards, integration, socio-economic costs and benefits, public adoption, ecosystem, and technology. Work Groups focused on cargo, passengers, the European Hyperloop Center, and future prospects manage these aspects.

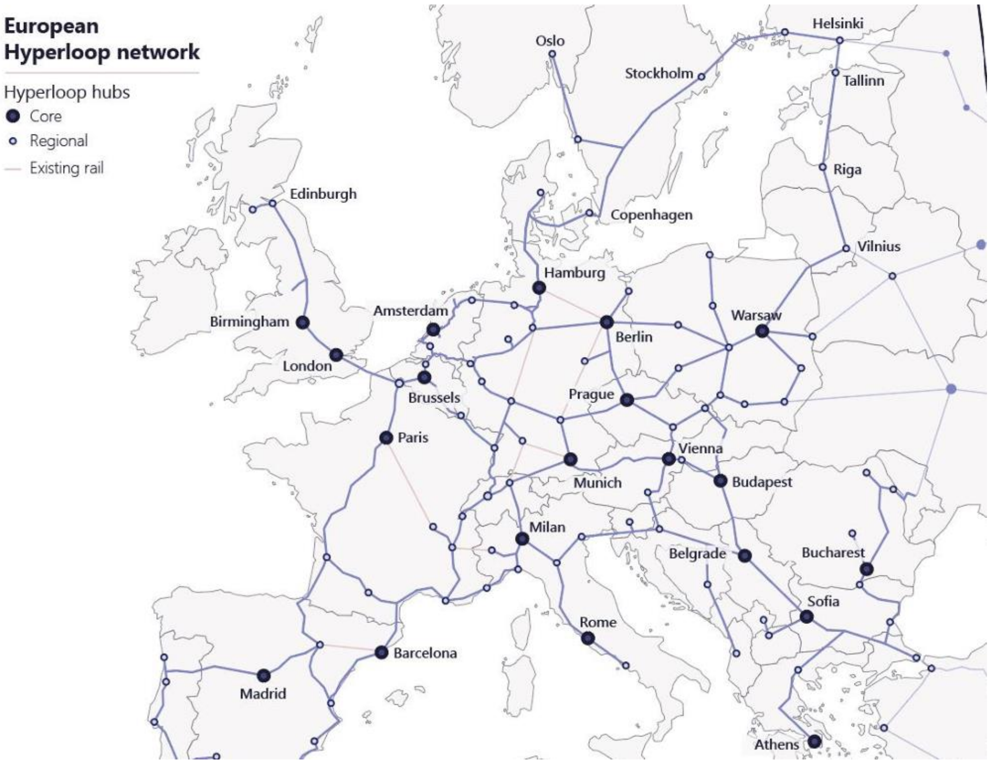
The Hyperloop could reshape transportation patterns and further connect Europe

- **Transformative reduction in travel time** because of the high speed that might be attained by Hyperloop enabling a transformation of travel and living patterns. For example, living 300 km away from your work.

- **Increased sustainability** because of efficient energy usage and no direct emissions, providing a cleaner alternative for air travel, trains and road transport.
- **Enabling growth:** the current infrastructure cannot accommodate the expected growth in demand.
- **Fewer externalities**: Hyperloop is expected to have fewer externalities than other modes of transport (less land use, less noise, fewer emissions, etc.).
- **Reduced energy-intensity per travelled km:** Hyperloop would have higher system capacity and therefore lower energy-intensity (energy use per travelled km) compared to current comparable modalities.
- **Promoting technology development:** various subsystems have potential spillovers to other transport modes and non-transport uses.

These advantages would enable the realization of a "Hyperconnected Europe," for which an initial vision was conceived, as depicted in the figure below. The envisaged network illustrates the scope of anticipated services throughout Europe, offering an first foundation for further development of potential hubs and corridors.

Figure 7: Vision for European Hyperloop network



Source: Hyperloop Development Program, Hyperconnected Europe: a vision for the European Hyperloop network

1.3 The Hyperloop playing field

Strategies differ between main technology developers

There are a range of different technology developers active differing in size and key technologies. Several important active players are presented below. Hyperloop One has recently ceased their activities, however, due to their size and role they played it is relevant to present their past activities and reason for seizing their activities.

Hardt Hyperloop (The Netherlands)

Founded: 2016

Employees: 42

Hardt was founded from the student team that competed in the SpaceX Hyperloop competition in 2016. Currently Hardt is seen as one of the leading European Hyperloop developers. Hardt has initiated the European Hyperloop Center, received an investment from the European Commission, and is working with European regulators to provide a pathway for the commercialization of Hyperloop technology in Europe and beyond.

Zeleros (Spain)

Founded: 2016

Employees: 58

Zeleros was also founded from a student team participating in the SpaceX Hyperloop competition. Like Hardt, they are focused on developing a full Hyperloop system and integrating most of the technology inside the pod. However, their focus is slightly different: Zeleros uses a track-side booster motor, meaning they have motors in the tracks, which Hardt does not have. Recently, Zeleros announced they will focus on electric mobility to generate income on the short term, but has stated they are still committed to developing a full Hyperloop system.

Nevomo (Poland)

Founded: 2017

Employees: 53

Nevomo has a different approach then most Hyperloop developers. Even though they see a future with a full Hyperloop system implementation, they propose a phased approach by (1) retrofitting current infrastructure to allow magnetic levitating trains with linear motors to travel over them (2) enclosing the infrastructure to reduce drag and (3) developing this enclosure into a full low-pressure Hyperloop tube. Recent tests have shown that their technology is able to magnetically levitate vehicles on existing train tracks.

Hyperloop TT (US)

Founded: 2013

Employees: 53 (and many contributors)

Hyperloop TT is one of the oldest technology developers and consists of 53 full time employees and many crowdsourced professionals who provide their time and knowledge in exchange for stock options. Recently HyperloopTT has unveiled a new plan to deliver cargo at high speed between freight terminals. HyperloopTT has a research center in France and several projects around the world that focus on passenger travel.

TUTR Hyperloop (India)

Founded: 2022

Employees: unknown

TUTR is a technology developer which originated from an incubation program of the Indian Institute of Technology Madras to further commercialized research and patents that were developed from research activities. TuTr Hyperloop has recently entered into a strategic partnership with Hardt Hyperloop to achieve interoperable Hyperloop technology.

CASIC (China)

Founded: 2017

Employees: unknown

The China Aerospace Science and Industry Corporation (a Chinese State Owned Enterprise) has been developing Hyperloop technology since 2017. Less is publicly known about their progress, however, recently they claimed to have achieved record speeds up to 623 km/h on their 2km long test track.

Hyperloop One (US)

Founded: 2017

Employees: 250

Hyperloop One (formerly Virgin Hyperloop) was the biggest technology developer which secured $450 million in funding. They had a test facility in Nevada with a test track of 500 meters long. They developed multiple feasibility studies, including connections between Helsinki – Stockholm and a route in Missouri. In 2022 Hyperloop shifted its strategy away towards cargo transport. In December 2023 it was announced that Hyperloop One will cease their operations, the main reason given was the failure to secure any contracts for building a working Hyperloop system. The broader effects of this on the Hyperloop industry are unknown at the moment.

Transpod (Canada)

Founded: 2015

Employees: 22

Historically, TransPod has been one of the major players in the Hyperloop industry. Since their inception, they have focused on increasing the capacity of the Hyperloop system. They achieve this goal by developing cargo partnerships with airports and freight operators, leveraging cargo during periods of lower passenger demand to enhance revenue potential. Additionally, TransPod is working on developing technology to enable pods to couple together, further increasing system capacity. TransPod has been planning to develop a test track in Droux, France, since 2019. However, due to a lack of funding, construction activities have not yet commended.

Swisspod (Switzerland)

Founded: 2019

Employees: 16

Swisspod, like many Hyperloop technology developers, originated from student competitions. With a strong emphasis on energy efficiency, sustainability, and cost reduction, their drivetrain technology is designed modularly to enable various system configurations. In October 2023, they began laying down the first tubes for their full-scale Hyperloop infrastructure in Pueblo, Colorado.

In 2023 several technology developers have joined forces in the Hyperloop Association

The Hyperloop Association is an organization uniting various companies in developing hyperloop technology. Founded by seven hyperloop pioneers (Zeleros, Transpod, Swisspod, Nevomo, HyperloopTT, Hyperloop One and Hardt), this association acts as a unified voice for the industry. Their mission is to:

- Act as the primary gateway for the sector, establishing itself as the leading organization for all matters related to hyperloop technology;
- Champion, advocate for, promote, and safeguard the interests of its members in all hyperloop initiatives;
- Utilize its specialized knowledge to offer advice and perspectives to decision-makers and stakeholders on hyperloop and related subjects.

The establishment of the association highlights the growing collaboration within the sector. Many players acknowledge the necessity of future interoperability and recognize mutual benefits as they concentrate on various aspects of the value chain.

Several smaller test sites exist, main challenge is moving to a full scale demonstration site

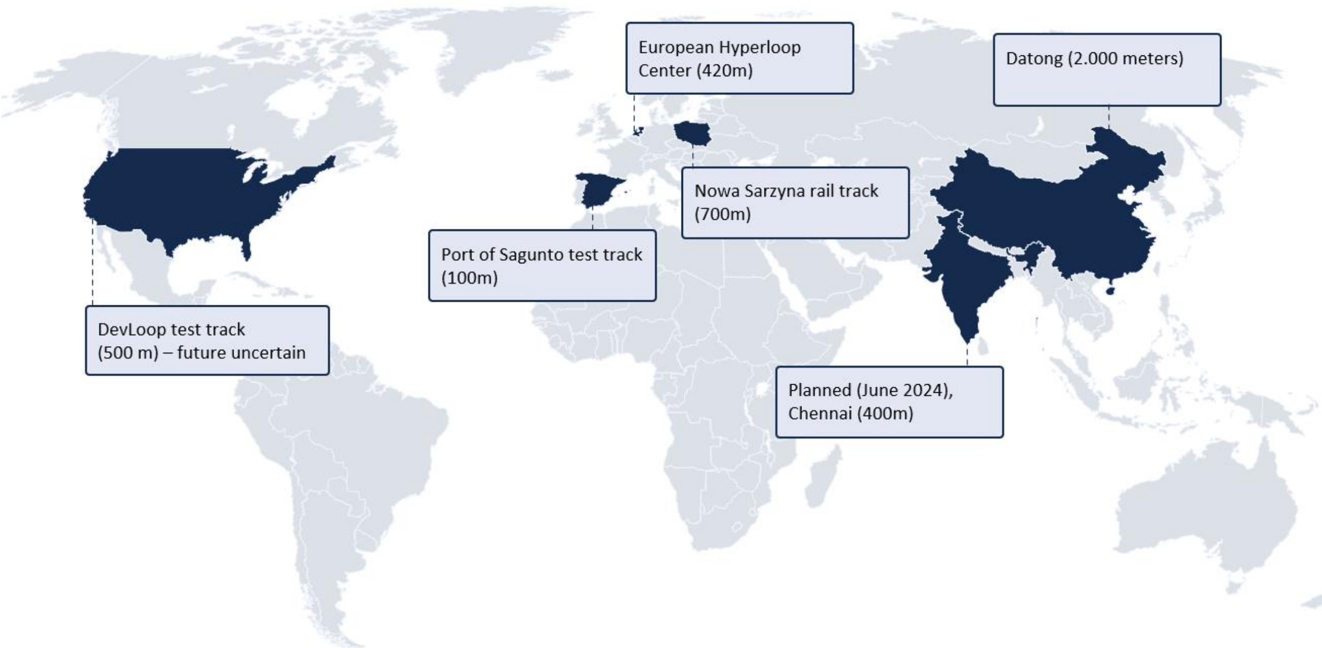
A number of small scale demonstration systems exist or are to be completed. The most important ones are shown in the figure below. The future of the DevLoop test track in the United States is uncertain, as it was mainly used by Hyperloop One, who is currently in the process of selling off all their assets.

Much can still be developed at these smaller test sites. After key technological components have proven themselves, the next step for most technology developers is to proceed to large-scale demonstration systems spanning around 5-10 kilometres.

The challenges around this step (the volume of funding involved, the size of the location and corridor needed, and the uncertain outlook on commercial rollout) will require cooperation between technology developers as well as substantial public sector support and commitment.

This means the next big leap for Hyperloop technology development appears to be within reach, but will depend on the fulfilling of these requirements for its success.

Figure 8: Most important test sites



Source: : Hyperloop Development Program, analysis consultant

The Benelux has proven to be an attractive location for Hyperloop development

- **Active private ecosystem:** an active ecosystem of private parties in the member countries, with a key technological developer and surrounding suppliers.
- **Willing public organisations:** public support, willingness and cross-border cooperation is essential for further development. In the Benelux, governments have invested in and developed policies to support the Hyperloop. They are generally willing to explore options, as demonstrated by the commissioning of this study. This aligns with the drive of the Benelux countries to develop more high-tech industries.

- **Public-private cooperation**: Hyperloop Development Programme stands out to demonstrate the eminent qualities of the Benelux to bring together technology development in a successful regional innovation system , public private partnerships and, of course, the European Hyperloop Center in Veendam, where testing and demonstration will soon commence.
- **Laboratory-like environment:** Many research institutes, congested public transport, spatial planning challenges, the need for new settlement patterns, and the necessity of providing clean alternatives for short-haul flights, along with improving cross-border train connections. The Benelux seems like the ideal laboratory for further developing the Hyperloop.
- **Innovative economies:** Benelux countries foster innovation, this is shown by the high positions in the European Innovation scoreboard (number 4,5 and 7). This means the countries can be considered innovation leaders, with Luxemburg specifically mentioned as 'strong innovator'. This is made possible by a strong knowledge sector consisting of universities, student teams and knowledge brokers.
- **Sustainable and more efficient cross-border transport:** sustainable alternative for short-haul flights. Additionally, Hyperloop is not affected by the interoperability issues on the rail network, which improves efficiency on cross-border connections.

1.4 This study report

This study report follows the following outline:

Chapter 2: What do different possible futures for Hyperloop development look like?

Chapter 3: What opportunities exist for Hyperloop cluster in The Benelux + NRW, and what are possible public sector actions?

Chapter 4: Where could cross-border connections and first proof-of-concept systems be developed between Benelux-NRW countries?

Chapter 5: Taken together, what strategic perspectives might Benelux-NRW policymakers consider in relation to Hyperloop development?

2. Possible Hyperloop futures

2.1 Scenario approach

Uncertainty and need for decisions on the short term require scenario thinking

The future direction of Hyperloop development is as yet uncertain.

Not only is the answer to the big question unknown (will one or more 'full' Hyperloop systems be developed successfully?), additionally the questions of timing (when and how fast will this occur), location and actors (where and by who will this be implemented) and development path (how will the system develop from first implementation onward) introduce further uncertainties.

Despite these uncertainties, an approach for public sector action across the Benelux-NRW policymaking process may be needed in the short term – whereby not taking further additional actions and leaving Hyperloop development to domestic and international markets and other governments within and outside of the EU can also be considered a (do nothing) approach.

Because of the uncertain future and the need to adopt a well-considered Benelux-NRW approach, this study proposes several long-term scenarios for the future development of Hyperloop. It does so to 'test' the attractiveness of outcomes from different approaches.

Main building blocks for scenarios: (i) degree of integration, and (ii) scope of application

Aside from the nature of implementations (partial system concepts or a 'full' Hyperloop) or the scope and volume of Hyperloop development (from an incidental implementation to ubiquitous roll-out in corridors or interconnected networks), the most important uncertainties are either:

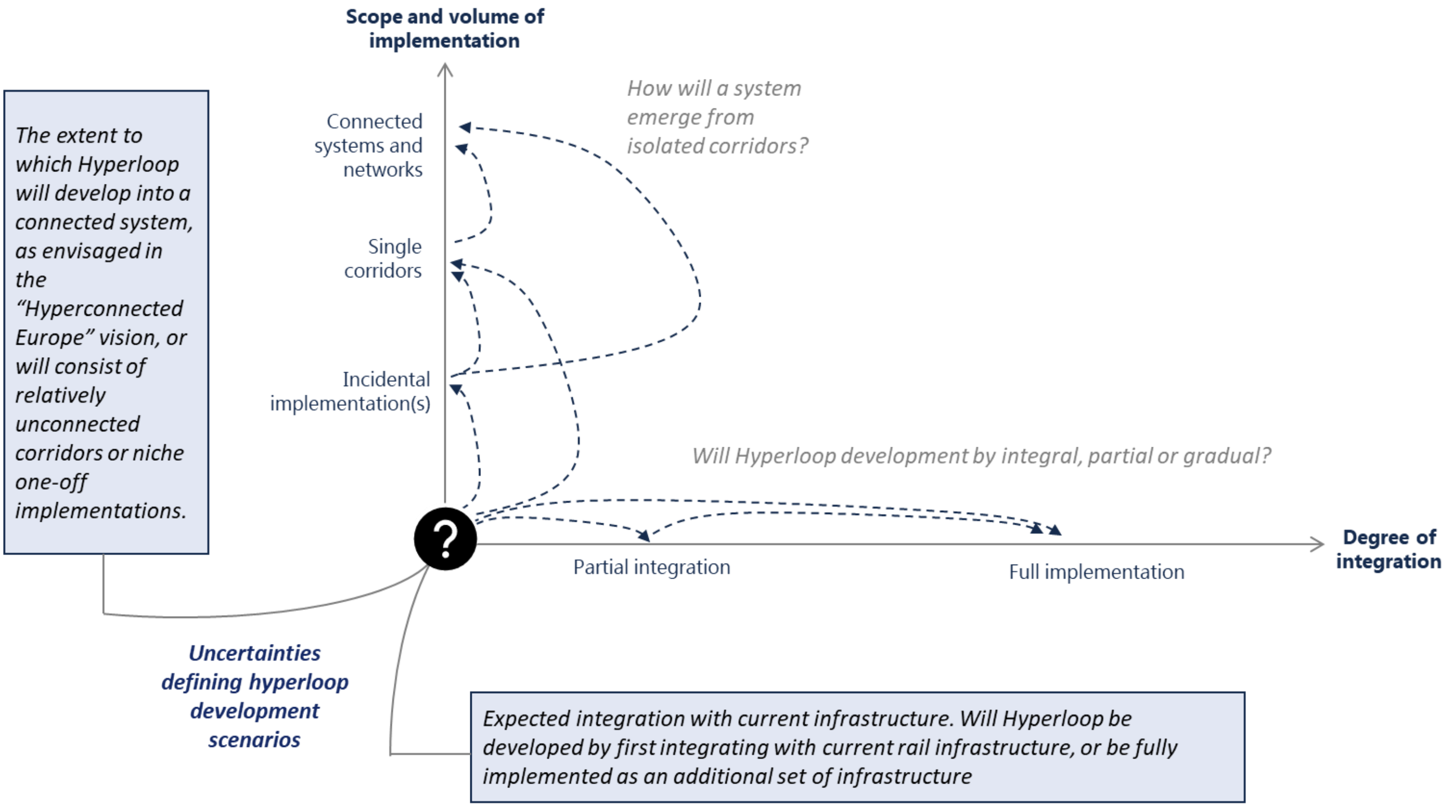
- Within governments' sphere of influence (where will the next step take place, which early pioneers are promoted and supported);
- Up to the market (which technologies will be developed successfully, which supply chains and clusters emerge as winners); or
- Less relevant for decision making (for example longer-term timing and developments, as the related public and private sector investment horizons are so distant that differences between possible development paths across this timeframe have little bearing on decision considerations today).

Therefore, the two main axes or 'building blocks' for Hyperloop development scenarios are (i) scope and volume of application and (ii) degree/level of integration, as further illustrated in the figure below.

Once these building blocks are established, it is evident that another relevant consideration must be the speed and pathway of Hyperloop development through different stages and scenarios thus established.

Will development go slow or fast, and will Hyperloop develop by upgrading current rail infrastructure or by eventually connecting isolated full Hyperloop systems into networks?

Figure 9: Axes of uncertainty as building blocks for scenarios



Source: Consultant

Four scenarios remain assuming "slow scenarios" are less relevant

The scenarios that are derived from these building blocks and shown in the subsequent figure below are reduced to a meaningful set of four scenarios.

This is done by discarding slow scenarios. Slow scenarios are defined as likely to involve such stretched-out timelines that they have no relevance for decision-making today as the first part of the Hyperloop development path corresponding to the scenario is already captured in another (comparatively shorter-term) scenario.

The scenarios included are:

1- **No progress scenario:** Hyperloop development does not progress beyond small- to real life testing and proof-of-concept systems;

2- **Niche application of integration with rail:** one or a limited number of corridors are developed and/or retrofitted with partial Hyperloop implementations (e.g. integration with rail through pod-block operations, maglev, etc.) are developed;

3- **Niche integral implementations:** one or eventually a limited number of transport corridors see full connection Hyperloop implementation, but in the bigger scheme of things Hyperloop remains a 'niche' phenomenon rather than a new universal modality; and

4- **Universal integral implementations:** Hyperloop technology is implemented 'full concept' (high frequency service patterns, low pressure system, magnetic levitation and a linear motor) in a large number of corridors and networks within the EU and in other global regions.

The following scenarios are considered as *slow* scenarios as defined above, and therefore are not included in analysis:

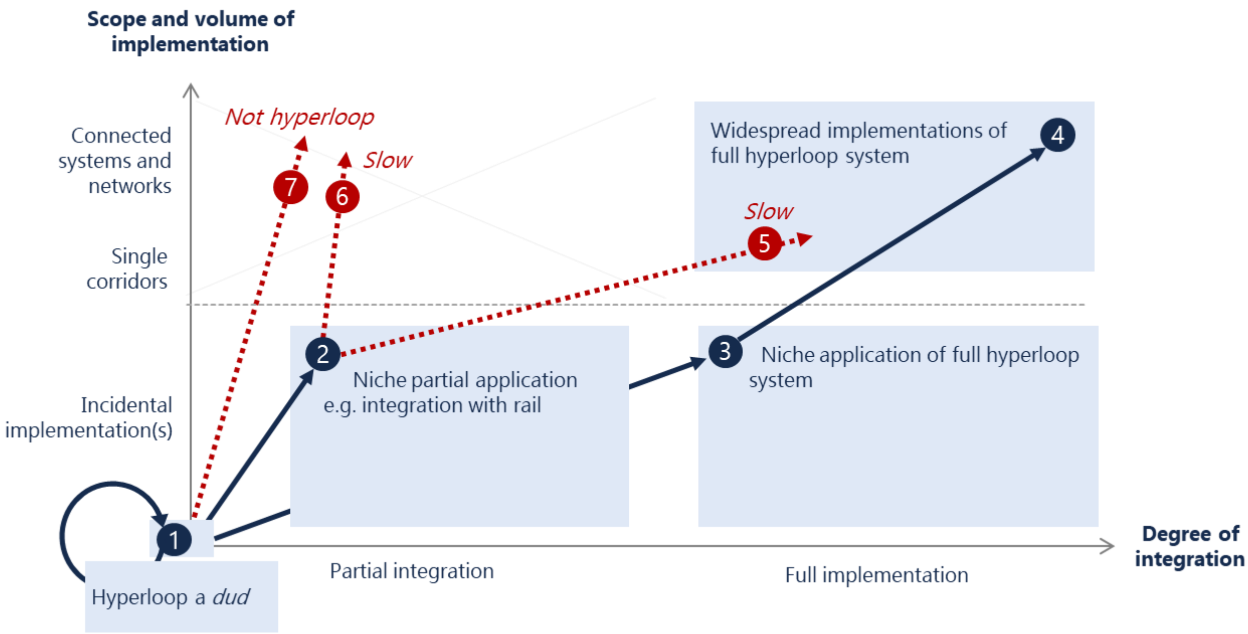
5- Slow transition via partial implementations [2] to eventually (long-term) widespread implementation of integral hyperloops;

6- Slow (long-term) widespread implementation of partial Hyperloop technologies into existing and/or new transportations systems; and

7- Widespread roll-out of partial Hyperloop solutions into existing and/or new transportation system.

The figure below demonstrates these four selected scenarios and three discarded scenarios. The scenarios are displayed in line with the axes of external or 'exogeneous' uncertainties that have been identified above.

Figure 10: Scenario development on identified uncertainty axes



Source: Consultant

Scenario 2 is maintained while scenario 7 is discarded although *both* concern a future of only partial implementations of Hyperloop, integrated with existing modalities into new or existing transport connections.

In reality, it may be difficult to distinguish a scenario 2 occurrence from the early stages of scenarios 3 and/or 4 which do concern full Hyperloop implementation()s).

For the purpose of this study therefore scenario 2, although it does not concern full Hyperloop implementation(s), is considered to have sufficient merit and is included in the set of scenario.

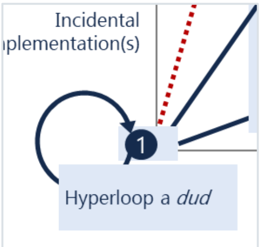
2.2 Conditioning factors

Proper analysis and use of the scenarios defined above requires an answer to the question: *which conditions need to be in place* to enable Hyperloop development to progress toward a specific scenario, or from one particular scenario through to another.

Some of these conditions concern external factors that are not easily steered or influenced by Benelux-NRW policy actions. Others may be relevant to defining a public sector approach and identifying appropriate actions.

We highlight a relevant selection of these conditioning factors in the paragraphs below.

To move forward in general



To realize progress beyond the current state of Hyperloop development and implementation (beyond scenario 1), it is clear that at-scale test systems and finally proof-of-concept implementations are needed.

These are relevant (i) to progress to full technology readiness for the full Hyperloop system, and (ii) to demonstrate to all stakeholder groups that Hyperloop is a technically feasible, operationally safe and functionally valuable modality and thus to support advocacy for further roll-out.

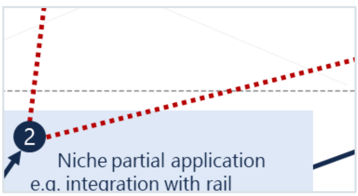
Therefore:

- Both test systems (whether public, private, closed or open access) and first proof-of-concept connections will require substantial public sector support to facilitate site and corridor right-of-way, licensing and permitting as well as development and operations subsidies.
- Furthermore, passenger transit seems to form the most viable use case for Hyperloop generally. As mass public transport is generally regulated and subsidized by governments, this necessitates proactive preparations and government interventions to plan and regulate Hyperloop as a new modality with a sufficiently viable future in public transport.

The implication of both of these factors and corresponding interventions is that Hyperloop seems likely to have the best chance of moving forward in the context of a public sector model i.e. with strong support, substantial funding, involvement and rulemaking by governments, government agencies, related (semi-)public bodies and transport operators.

Additionally, both factors involve actions within the Benelux-NRW scope of action should the respective governments decide on investing in moving Hyperloop forward. These may therefore be elaborated as (part of) a potential Benelux-NRW approach to Hyperloop development.

To move beyond partial implementations



Moving forward, Hyperloop may see first progress in one or several partial implementations (applying only part of the full Hyperloop concept to retrofit existing transport systems or in new systems).

This involves parts of the Hyperloop technology concept which may be ready for implementation, or indeed which may already have a track record of implementation in transport systems or other applications – lowering the barrier to implementation compared to a full Hyperloop system which contains a larger number of components which separately and combined need to achieve sufficient readiness.

Factors which may moderate and condition progress from one or multiple partial implementations to implementation of 'full' Hyperloop systems include at least:

- Partial implementation or retrofitting of Hyperloop technology parts to improve existing systems is not seen by travellers and service operators as bringing significant-enough benefits or step-change in travel patterns. It therefore does not reach significant implementation volumes and thereby does not reduce the strength of the case for full Hyperloop technology as a new transport modality.
- No competing new modalities are introduced, nor do existing modalities such as air travel develop new rivalling features (e.g. through the successful scaling of low-emission aviation) that undercut the case for full Hyperloop technology as a new transport modality.
- Committed public and/or public-private investments in full Hyperloop test and demonstration systems to proof the viability, safety and attractiveness of full Hyperloop systems as a new transport modality;
- Active promotion of solutions to integrate the footprint and infrastructure requirements of full Hyperloop systems in into existing corridors, transportations infrastructures and built environments (how to combine with highway road infrastructure, how to integrate with railway systems, etc.?);
- In case of physical, functional and/or operational integration, locking in commitment, cooperation and ownership of existing infrastructure managers and service operators concerned; and
- Large scale/volume funding programs (TEN-T, Federal Highways, etc.) with the scale and incentives to attract investment and development effort towards one or several regional Hyperloop networks are geared towards the system concept of an 'integral' Hyperloop technology.

This introduces various external factors and mostly reconfirms the importance of public sector (rather than private sector) actions as instrumental to the progress of Hyperloop development.

Again, such actions are within the Benelux-NRW scope in case its governments decide on investing in moving Hyperloop forward. These may thus be elaborated as (part of) a potential Benelux-NRW approach to Hyperloop development.

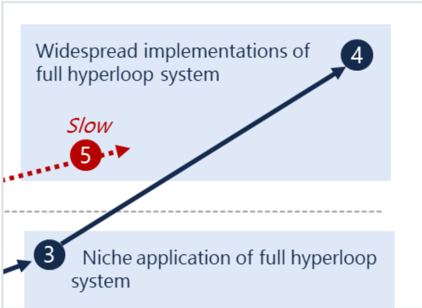
To move beyond niche implementations

In many discussions concerning the potential of Hyperloop development progressing, the TransRapid scenario or more generally the maglev rail scenario looms large.

In such scenarios, which played out in the aforementioned case(s), a new integral technology concept (akin to how Hyperloop combines technologies into a new package) is introduced but never moves beyond one or several 'incidental' implementations.

As such the modality remains a 'niche' modality without corridor and/or network development occurring at scale. It thus lacks the volume to support the formation of invested and committed supply chains and clusters with the potential for long-term commercial and economic value creation.

Conditioning factors moving the state of Hyperloop development along beyond the 'niche' modality include:



- A concerted effort by Hyperloop technology developers within the EU and beyond it to strive for standardization, harmonization and convergence of Hyperloop technology formats to assure maximum interoperability between different providers, systems, regions, etc. Technology developers have made an initial effort in this area through collaboration within the Hyperloop Association.
- A similar drive by designated regulatory authorities across the most important manufacturing and implementation markets (including but not limited to the EUs internal market) to develop new and maximally harmonized standards and requirements;
- No competing new modalities are introduced, nor does concurrent partial Hyperloop implementation overtake the full system as the most attractive option, nor do existing modalities such as air travel develop new rivalling features (e.g. through the successful scaling of low-emission aviation) that undercut the case for full Hyperloop technology as a new transport modality.
- To the extent these are not developed already: active promotion of solutions to integrate the footprint and infrastructure requirements of full Hyperloop systems in into existing corridors, transportations infrastructures and built environments (how to combine with highway road infrastructure, how to integrate with railway systems, etc.?);
- In case of physical, functional and/or operational integration, locking in commitment, cooperation and ownership of existing infrastructure managers and service operators concerned; and
- Large scale/volume funding programs (TEN-T, Federal Highways, etc.) with the scale and incentives to attract investment and development effort towards one or several regional Hyperloop networks are geared towards the system concept of an 'integral' Hyperloop technology.

This introduces once again various external factors and mostly reconfirms the importance of public sector approaches (rather than private sector) as instrumental interventions with concern to other conditioning factors. Again these interventions are within the Benelux-NRW scope of action should the respective governments decide on investing in moving Hyperloop forward and thus may be elaborated as (part of) a potential Benelux-NRW approach to Hyperloop development.

2.3 Implications for public sector action

Across the board, many of the conditioning factors for progressing Hyperloop development highlight the need for public sector interventions.

The most common themes amongst these are the following:

- Progress in general is conditioned on demonstration of the viability and attractiveness of Hyperloop technology – whether this concerns partial or integral Hyperloop concepts. Show it works, at scale and in 'real life' travel use cases.

- Especially relevant to densely populated and built-up regions like the Benelux-NRW: development of Hyperloop systems along longer corridors, even with a limited footprint in cross-section, requires substantial creativity and flexibility by many stakeholders to allow for integration of its new infrastructure(s).
- All of the above requires substantial funding for a longer period of time. Private finance is unlikely to be sufficient for pulling the full weight of what is needed given both:
    - (i) The expected funding outlay for testing and proof-of-concept development, *without* the guaranteed outcome of revenue business cases in the short- to medium term); as well as
    - (ii) Viability gaps associated with mass passenger transit systems in general which likely will also occur in the case of full Hyperloop implementations.
- Finally, regional cooperation to accelerate cross-border corridors and network development is crucial – at the Benelux-level but especially across larger regions. This holds true for the EU and neighbourhood countries, for North-America (or at least for cross-state/federal connectivity cooperation in the US) and former CIS countries, etc. The South-Asian subcontinent might be one of the few exceptions where substantial scale of network development can be achieved within (India's) national borders.

  This is a precondition to the rapid and jointly-funded achievement of scale, interconnectedness and harmonization. Regional cooperation within Benelux or EU frameworks will also very likely result in (more) access to EU funding sources.

These implications for public sector action, with particular relevance for the Benelux-NRW, will feature prominently in the following analysis of cluster development prospects, proof of concept connections and overall potential strategic perspectives and approaches for the Benelux-NRW.

3. Cluster development

3.1 About clusters

This study explores the potential of cluster and supply chain development related to Hyperloop technology with a focus on the potential establishment of innovative and high-tech manufacturing in the Benelux-NRW.

This chapter is based on a broad understanding of its nature, conditions and outcomes (in terms of value creation for the host city/region/country), below.

Economic clusters are assumed to drive economic growth through increased employment and productivity[1]

- Clusters are geographic concentrations of interconnected companies and institutions in a particular field. They are critical masses – in one place – of above-average success in particular fields.
- In the past, competition primarily revolved around input costs, locations with cheaper access to inputs – such as a natural harbour or access to inexpensive labour—provided areas, and the companies within them, with a comparative advantage. However, in today's economy global sourcing enables companies to reduce many input-cost differences, diminishing the relevance of input costs. Instead, competition is more dependent on maximizing productivity (partly through developing and commercializing innovative products).

Economic clusters have the potential to increase productivity through better sourcing of inputs and higher levels of innovation[1]

- *Sourcing inputs*: being part of a cluster allows companies to operate more productively in sourcing inputs; accessing information, technology, and needed institutions; coordinating with related companies; and measuring and motivating improvement.
- *Innovation (or future productivity)*: economic clusters can stimulate innovation because the combination of knowledgeable organizations and individuals provides a clearer insight into the market compared to isolated competitors. Clusters also offer the capacity and flexibility to act rapidly. Companies within a cluster can often source necessary resources more quickly to implement innovations. Additionally, local suppliers and partners are closely involved in the innovation process, ensuring a better alignment with customers' requirements. Presence and/or 'membership' of a cluster means partaking in exchange of innovations.

Clusters extend beyond direct supplier relations

- Clusters go beyond the core organizations and their suppliers, often including manufacturers of complementary products and companies in related industries sharing skills, technologies, or common inputs. Additionally, many clusters include governmental and other institutions, such as universities, standards-setting agencies, think tanks, vocational training providers, and trade

[1] Clusters and Competition, Michael Porter, 1998

associations. These organizations offer range of services which increase competitiveness of the cluster through training, education, information, research, and technical support.

Cluster can be supported, but not created by governments

- A cluster’s roots can often be traced to historical circumstances. The Dutch and Belgian transportation cluster owes much to their central location, an existing network of waterways, the efficiency of their ports and the skills developed historically.
- Existence of related industries, or even entire related clusters provide a breeding ground for new clusters. Examples include Solvay's development rooted in Belgium's existing coal and salt industry, ThyssenKrupp’s automotive activities based on the existing steel industry and the development of ASML from a division of Philips. New clusters may also arise from one or two innovative companies that stimulate the growth of many others, Hyperloop developers could play such a role.
- The success of clusters appears to be determined by unique local conditions, the exact mix and interaction of which often eludes us, even for existing clusters. In free market economies, clusters generally cannot be imposed or created by policy makers. Clusters are not sufficiently engineerable and there are no clear set of rules to justify assumed cluster potential.
- Therefore, governments, working with the private sector, should reinforce and build on existing and/or emerging clusters rather than attempt to create entirely new ones.

3.2 Imagining Hyperloop clusters

Hyperloop development is still in its early stages, with several technology developers working to advance TRL levels and conduct feasibility studies to showcase added value.

Consequently, statements regarding the potential characteristics, conditions and/or outcomes of a Hyperloop cluster or supply chain are premature.

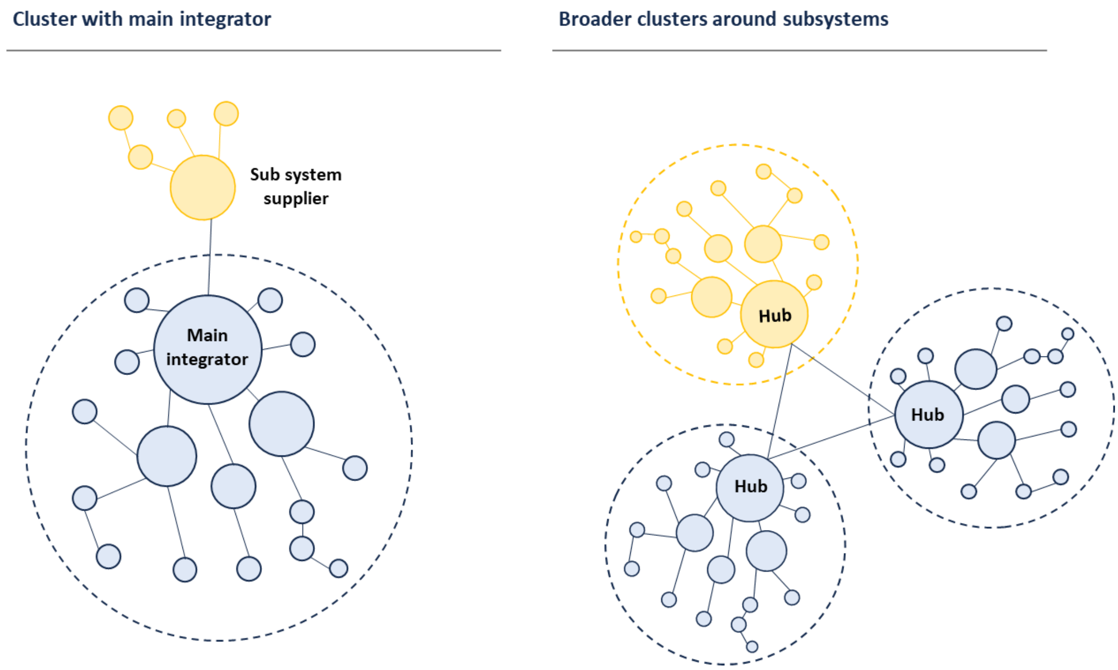
Nevertheless, when examining the current characteristics combined with experience from similar industries (e.g. rail rolling stock manufacturing) some insights can be gained.

Benelux-NRW cluster development could focus on specific subsystems

- The form of manufacturing clusters is dependent on market conditions (dominance of players, strength of patents, complexity of components / subsystem, etc.), and political decision making (government support, standard setting, etc.).
- Because of the high level of complexity it can be expected that one or more dominant parties emerge in Hyperloop clusters. This can take several forms, it could be that there is one main integrator, or several interrelated clusters focussing on specific technologies / building blocks of the Hyperloop system.
- In a cluster with one dominant integrator it is unlikely that the Benelux-NRW region will host this player due to the required scale of production and the general tendency of integrators to (re)locate to the most voluminous markets. This means that for smaller regional economies, in

all possible cluster scenarios, the chances of success are highest when focussing on specific technologies / subsystems. This is shown in yellow in the figure below.

Figure 11: Possible forms of Hyperloop cluster

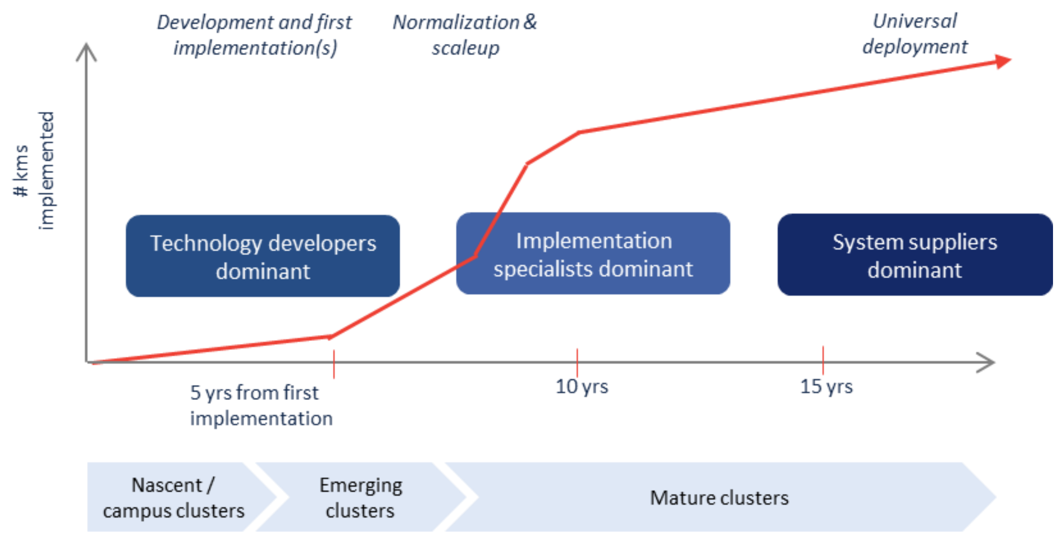


Source: Consultant

If Benelux-NRW aim to play a role in future economic clusters, it is key that nascent / campus clusters are enabled.

- In the short term, technology developers will continue to hold dominance, supported by an ecosystem of public, research, private, and public-private organizations. However, as systems are implemented, it is anticipated that these roles will evolve. Drawing from experiences in the railway industry, the figure below illustrates a potential shift.
- In this initial phase, it's not anticipated that real economic clusters will emerge, as they typically require economies of scale. It is only when suppliers and larger manufacturing companies feel confident about the actual implementation that such clusters are likely to begin forming.
- If the Benelux-NRW region aims to host future economic clusters centred around key technologies of a Hyperloop system, it is essential to enable the current campus and nascent clusters. This will allow them to contribute to larger emerging and mature economic clusters in the long term as economic clusters build on existing capabilities and players.

Figure 12: Possible dominance of players over time



Source: Consultant

3.3 Relevant examples

In the following section examples of the discussed clusters and developments are provided to extract lessons for possible Hyperloop clusters. Clusters have a very specific historical and location dependent context, this means the lessons extracted are not golden rules but can guide governmental action.

BRAINPORT EINDHOVEN

Campus cluster - Brainport Eindhoven [2]

Background

- Around the turn of the century, Philips divested several companies / departments (mainly around semiconductor, optics and X-ray technologies). These divestments formed the basis for several new deep-tech companies. In the field of knowledge institutions, new research institutes such as Holst Centre and DIFFER were founded (in addition to TU/e).
- After economic downturn several ambitious programs were developed by knowledge institutions, businesses and government. This resulted in structured 'Brainport' governance with equal power distribution that allows for strategic alignment.
- Most companies in the Brainport area develop advanced technical systems and products for industrial markets. These products and systems tend to be of a 'high complexity, low volume' nature. Brainport profiles itself in this field primarily in deep-tech entrepreneurship.
- A deep-tech entrepreneurship combines multiple technologies in new solutions for healthcare, energy storage, robotics, or internet of things, for example. By using unique and well-protected innovations in, for example, new synthetic materials, artificial intelligence, embedded software, mechatronics, electronics, photonics, and fine mechanics. Physical co-

[2] Succes van Brainport Eindhoven is niet eenvoudig te repliceren, Sjoerd Romme, 2022

location of academic and industrial researchers allow for easy collaboration and 'implicit spill-overs'.

Lessons learned

- **Co-location of R&D activities:** innovation in the Brainport area can be traced to the presence of a number of hotspots for innovation and entrepreneurship. These location-based hotspots promote the transfer of implicit knowledge and, moreover, the physical co-location of R&D is a crucial condition for effective collaboration between academic and industrial researchers.
- **Public coordination can help:** Brainport's cooperation formula includes a professional and resistant approach to regional policy-making that fits into a long cooperative tradition in this region.
- **Unique local conditions:** The competitiveness and stickiness of the Brainport cluster is dependent on a range of complex social systems at strategic, tactical and operational level, deep-tech entrepreneurship provides a profile that does justice to the regional and social history of the area.

Developing specific subsystems - partnership of ASML and Zeiss -

Background

- ASML is a Dutch company providing lithography machines for semiconductor companies all over the world. ASML also provides service material for their machines for all global customers
- ASML has an extensive supplier network of around 4.800 suppliers with up to 85% of the systems in the machines procured from these suppliers. There is a local cluster surrounding the company, but there are also strategic partnerships where ASML partially owns suppliers.
- ASML has acquired a 24.9 per cent minority stake of Germany-based Carl Zeiss SMT, a business group of Carl Zeiss AG (Zeiss), for €1 billion in cash. The main objective of this agreement is to facilitate the development of the future generation of extreme ultraviolet (EUV) lithography systems that will enable the semiconductor industry to produce much higher performance microchips at lower costs.

Lessons learned

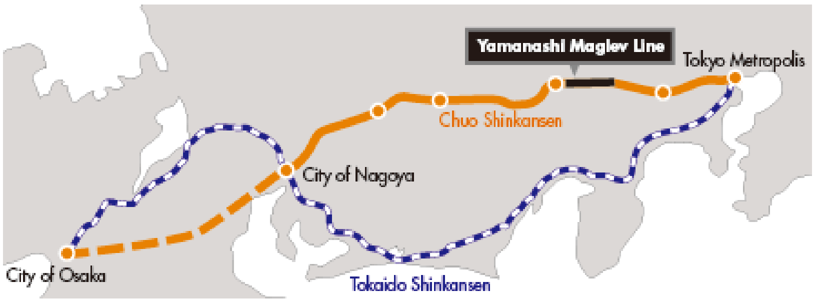
- **Connecting into larger supply chains:** there are opportunities for clusters at distance of the main system integrator. As many of the systems are procured, clusters can be developed at distance of the main system integrator when they are revolve around a key technology.
- **The importance of patents:** for high-tech products patents are important. It makes sense to track main patents registered in the countries to see what key technologies could provide a basis for a potential cluster.
- **Building on what is there:** the industries were built on industries that were, at least partly, already there. This underlines the argument that clusters don't just appear. They are linked to the industries that are already present.

NIPPON SHARYO Growing from nascent to emerging cluster - Maglev in Japan[3]

Background

- Maglev, short for magnetic levitation, is a train propulsion technology that uses powerful magnets to lift and propel trains above the track, eliminating the need for traditional wheels and axles. By levitating the train and using magnetic fields to propel it forward, maglev trains can achieve higher speeds and smoother rides compared to conventional rail systems, making them a promising solution for high-speed transportation
- Chuo Shinkansen maglev system is planned to connect Tokyo and Nagoya somewhere after 2027. Testing and research around maglev technology and train prototypes was focused around on the Yamanashi Maglev line. Central Japan Railway Company oversees development of the line. Rolling stock and system manufacturing focuses on Nagoya region and is done by companies such as Nippon Sharyo and Kawasaki.
- The Maglev line connects the test track, industrial cluster and knowledge centres in Tokyo. This meant that both research organizations and manufacturing companies had easy access to the test facilities, and that the test line serves as the basis for further development of the line.
- Around 2017 Mitsubishi abandoned the Maglev project, resulting in a setback. Luckily, Nippon Sharyo, a subsidiary of Central Japan Railway Company, was also heavily involved and is now leading train development. Together with companies such as Kawasaki and the surrounding supply network they are manufacturing the trains.

Figure 13: Test track and proposed maglev route



Source: Central Japan Railway

Lessons learned

- **Combining cluster and test track:** taking the next step entails creating a longer test track. This also marks a pivotal moment for development of clusters, companies involved in development of this test track build up valuable knowledge and capabilities which could enable them to develop a dominant position in the future.
- **Risk of one dominant player:** if technology development is dependent on a specific company, and / or is not embedded in local conditions, there is a large risk of the opportunities for clustering to fall away.

[3] Succes van Brainport Eindhoven is niet eenvoudig te repliceren, Sjoerd Romme, 2022

Takeaways for cluster development

Analysis is made on combination of expected innovation and current competitiveness

- It is unlikely that the Benelux-NRW market has the capability to retain the integrator role and/or total system development due to the required scale of production and the general tendency of integrators to (re)locate to the most voluminous markets. If Hyperloop materializes at scale, it is more plausible that clusters will form connecting to the broader global supply chain, or that one of the technology hubs could be established here.
- Considering the current capabilities, the absence of scale (both in market size and production capabilities), it is logical to seek out technologies characterized by high-tech, low-volume production. Innovation is crucial for such products. Therefore, in the next section, our emphasis lies on exploring innovative opportunities for subsystems.

  These subsystems must, at the very least, possess the following attributes:

  - High-tech;
  - Non-existing (for example in train industry); and
  - Further development necessary.
- Clusters build on what is there. Therefore, an indication will be given on the current competitiveness of the Benelux- NRW on the different Hyperloop system.

Implementation drives future competitiveness

- The development of economic clusters in industries where governments are the primary consumers results from a complex interplay between market conditions and public action. While many economic clusters with private entities as main customers arise organically within specific locations and historical contexts, those serving transport infrastructure and services predominantly rely on government involvement. Demand in this sector is significantly influenced by public action, as governments often determine the main market and investments. It is not incidental that train manufacturers emerged in countries that made substantial investments in railways
- It's not a prerequisite for the proof of concept connection, knowledge institutions, and business headquarters to be in close proximity. In a sense, all of the Benelux-NRW region can be considered sufficiently close for clustering. However, it is important that all these organizations are connected to future developments.

Clusters are not made by governments but can be supported by them

- Governments can play an important facilitating role in cluster development. Through investments and coordination ecosystems can be nurtured.
- To ensure the sustainability of economic activity, it makes most sense to invest in ecosystems rather than focusing solely on individual players. By fostering valuable supplier relationships between technology developers and their suppliers, context-dependent competitive advantages can be cultivated.

3.4 Possible Hyperloop clusters

To arrive at a shortlist of potential technologies around which clusters could form in the future three questions are answered:

- First, the key technologies are clustered into systems around which clustering could occur. They are kept large enough to allow for a diverse set of outcomes, as it is uncertain where most value will be created and/or spillovers could occur.
- Secondly, expected innovation is examined for these clusters. If there is a low extent of expected innovation, either there is no way to develop a competitive edge, or current competitive companies can step in. Both of these scenarios would require limited government action. The chances for clustering is larger for subsystems where significant innovation is expected as this provides an opportunity for developing a competitive edge.
- Finally, the remaining systems are matched with current manufacturing excellence in the Benelux-NRW.

When combining the last two questions (expected innovation and competitiveness), courses of action can be developed, as shown in the figure below.

In the following sections the subsystems are defined step 1) and scored on expected innovation (step 2) and competitiveness (step 3). Afterwards, the types of support which can be given are discussed in more detail.

Figure 14: Courses of action in relation to competitiveness and expected innovation

Competitiveness \ Expected innovation	Low	Medium	High
High	**Connect to development** No support needed	**Monitor and support** High chance of involvement with medium value add	**Prioritize support** High chance of involvement with high value-add
Medium	**Ignore for now** Lower chances of involvement, current players can copy current products	**Ignore for now** Lower chances of involvement, current players have a head start	**Monitor** Lower chances of involvement as current players have a head start, but high value add makes it interesting to monitor progress
Low	**Ignore for now** Lower chances of involvement, current players can copy current products	**Ignore for now** Lower chances of involvement, current players can copy current products	**Ignore for now** Lower chances of involvement, current players can copy current products

Source: Consultant

Step 1: Categorizing the Hyperloop technology into subsystems

For this analysis, the Hyperloop system is divided into the following subsystems.

These subsystems differ slightly from the categorization according to Hypernex[4] , but they can be aligned. For future analyses, it's important to ensure consistent categorizations are used for accurate comparisons and assessments.

Table 2: Hyperloop subsystems

System	Subsystem	Explanation
Pod	Vehicle structure and systems	Vehicle structure and onboard technologies / systems such as onboard power, doors, pressure system, atmospheric control, evacuation, interface and battery system.
Guideway	Guidance, propulsion and levitation	Rails that enable levitation and propulsion of the pods. Technologies differs between developers, but most bear many resemblances to technologies used by Maglev trains. .
	Switches	Technology which enables pods to change lanes at high speeds. This system consists of a magnetic system that enables the pod to switch from one guidance system to another.
Tube structure	Regular tube segments	Regular tube structure including straight segments, curved segments and inclined segments.
	Airdocks, airlocks and low pressure related systems	Passengers and cargo board and exit the vehicles using specially designed airdocks. These airdocks function as passageways between the platform and the vehicles, allowing payloads to move in and out. When the vehicle reaches the platform, its doors align with the airdock to form a secure seal. Once this seal is established, both the airdock and vehicle doors can be opened, providing access from the platform to the vehicle[5]. Airlocks are devices equipped with gate valves, and are expected to remain a necessary component for maintenance. Other low pressure systems consist of air pumps to reach low pressures inside the tube.
Systems		Systems that enable operations of a system including systems related to safety, security, energy, air evacuation, IT / control systems, coms and systems integration.
Buildings		Buildings such as terminal buildings (passenger interface, platform, airlock connection, services, circulation), energy centres, hangar, and offices.
Supporting structure		Structures which support the tunnels, above- or belowground, such as pylons, shallow buried, foundations, sheet piles, tunnels, dynamic jacks.

Source: Consultant

[4] https://cordis.europa.eu/project/id/101015145

[5] Hyperloop Progress Paper, Hardt Hyperloop

Some subsystems are connected to more than one system, as they consist of technologies affecting both systems (for example switches) or competing technologies are under development (for example guidance, propulsion and levitation systems).

Step 2: Expected innovation

Expected innovation for the identified subsystems is examined by considering the extent to which further development is necessary (is there an opportunity to become a standard setter, instead of merely following existing standards), whether technologies are closely linked to existing technologies (is it reasonable to expect that existing players in related industries will be able to copy their existing products / capabilities when Hyperloop materializes) and whether the systems are of a complex / high-tech nature.

Table 3: Subsystems room for innovation

Subsystem	Room for innovation	Explanation
Vehicle structure and systems	**Medium-High**	**Development necessary**: yes materials that can withstand the conditions and are light enough are still in development. Onboard systems and technologies are also in development, however, innovation is dependent on the extent to which technology will be inserted into the pod instead of inserting more technology in the rails. **Copyable:** partly, materials that can withstand extreme conditions and are light exist in a variety of industries (for example the aviation industry). **High-tech**: yes, the level is dependent to which the technology will be inserted into the pod.
Guidance propulsion and levitation	**High**	**Development necessary:** yes, development of the technology is necessary and no company has yet proven to be able to run a stable 700 km/h+ magnetic guidance system. **Copyable:** partly, as Maglev technology uses similar systems, the extent to which systems can be easily translated from this existing technology is dependent on the system that will become dominant. Technology developers currently have different ideas on this. **High tech:** yes, the system is a complex combination of different materials and products into an electromagnetic suspension system.
Switches	**High**	**Development necessary:** yes, technologies to enable switching at high speeds is crucial and still very much in development. **Copyable**: no, there is no current technology that is similar enough to be considered as a template that can be adapted to the Hyperloop needs. **High tech:** yes, the system is complex, especially as safety demands will be stringent.
Regular tube segments	**Low - Medium**	**Development necessary:** yes, the preciseness of tube construction, especially for curved segments, can currently only be achieved. By a handful of companies. New ways of developing the tubes, based on

		skeletons with different materials than steel could also become relevant. **Copyable**: partly, steel tubes are manufactured all around the world. But not with the required preciseness nor dimensions, if other concepts (such as a skeleton with different materials) are developed copyability decreases. **High tech:** differs, again dependent on the development of new techniques and concepts.
Airlock and low pressure related systems	**Medium**	**Development necessary:** yes, the efficiency with which the low pressure is achieved needs to be further developed. **Copyable**: yes, there are many technologies available for the creation of vacuum / low-pressure environments. **High tech:** yes, the components and systems are technologically advanced, also because of the high safety requirements.
Systems	**Medium**	**Development necessary:** yes, the Hyperloop system requires new technologies regarding safety, security, energy, air evacuation and system integration, **Copyable**: partly, some of the systems could be considered of a similar nature to current Maglev and train systems. **High tech:** yes, systems will consist of a complex interplay between hardware and software.
Buildings	**Low**	**Development necessary:** partly, some buildings, for example terminals and maintenance areas should be newly developed. Others are more readily available. **Copyable**: high, buildings for public transport and airports could be considered similar. **High tech:** no, even though systems will be installed in buildings, the buildings in itself are not considered high-tech.
Supporting structure	**Low**	**Development necessary:** no, tunnels and elevated infrastructure are already existing. **Copyable**: yes, from current applications of buried and elevated infrastructure. **High tech:** no, the supporting structures are considered passive infrastructure.

Source: Consultant

Step 3: Indicative competitiveness

Below is a tentative assessment of current competitiveness regarding the subsystems. Competitiveness may vary among countries for some subsystems. However, differing competitiveness does not imply the absence of opportunities. While limited competitiveness may exist for certain subsystems outside of key technology developers, clusters could still emerge through inter-country cooperation and learning from current leaders.

The indicative competitiveness is based on existing key players and discussions with relevant stakeholders. Additionally, variations in previous and current engagement between countries complicate this assessment, thereby limiting the accuracy in determining the roles and competitiveness of current industries in the member countries. Thus, this list is highly indicative, and further exploration is warranted.

Table 4: Benelux-NRW subsystems competitiveness

Subsystem	Belgium	NL	Lux	NRW	Combined
Vehicle structure and systems	**High**	**Medium-High**	**Medium-High**	**High**	High
Guidance propulsion and levitation	**Low**	**Medium-High**	**Low**	**Medium**	Low / Med / High
Switches	**Low**	**High**	**Low**	**Low**	Low / Med / High
Regular tube segments	**High**	**High**	**Medium**	**Medium**	Med / High
Airlock and low pressure related systems	**Medium**	**High**	**Medium**	**High**	Med / High
Systems	**Low**	**Medium**	**Medium**	**Medium**	Low / Med / High
Buildings	**Medium**	**Medium**	**Medium**	**Medium**	Med
Supporting structures	**High**	**High**	**Medium**	**High**	Med / High

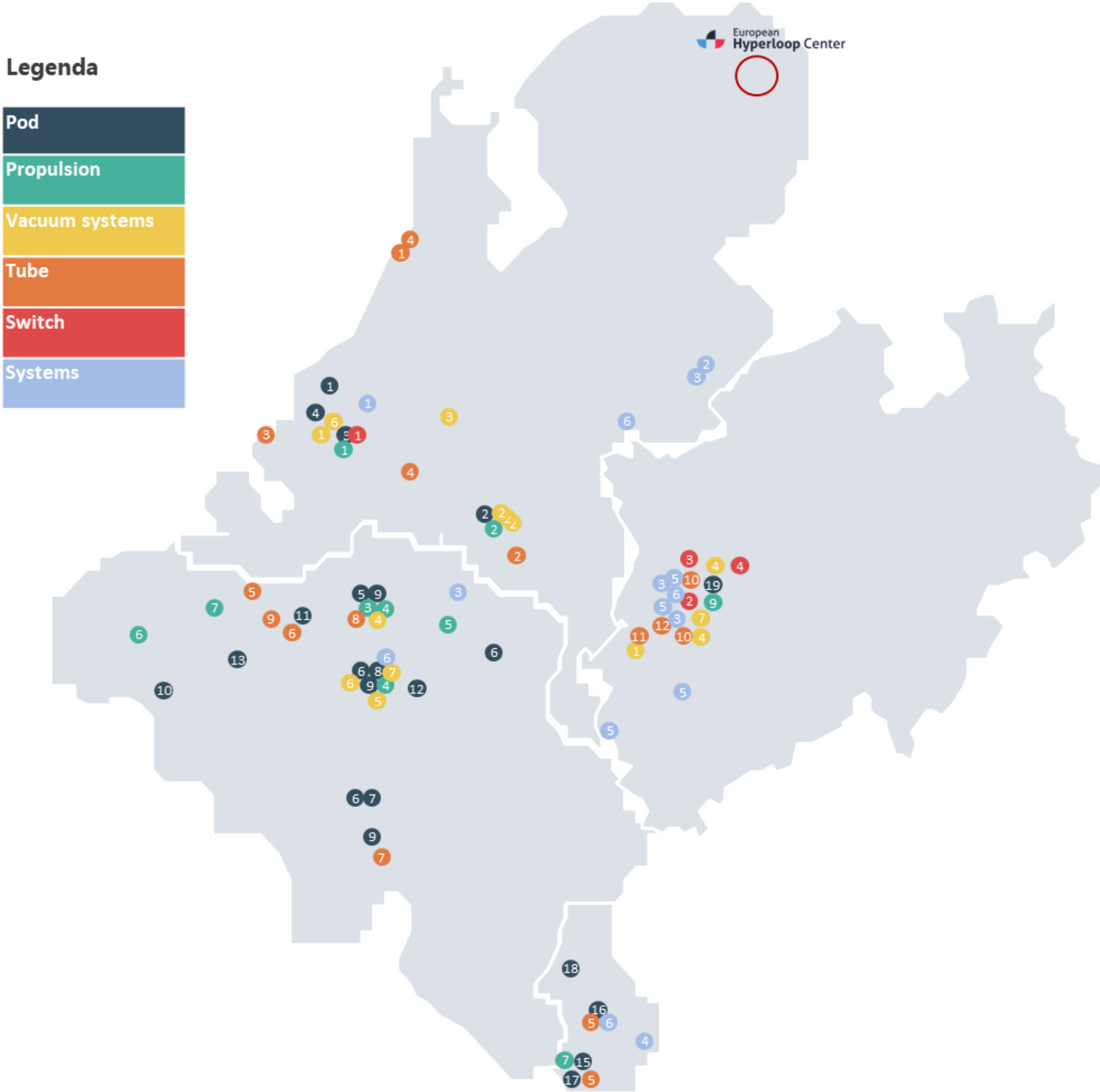
Source: Consultant

An indicative map and list of existing companies with larger scale manufacturing capabilities can be found below in the next section.

Overview of identified companies

Through interviews with stakeholders, an indicative overview of existing companies with larger-scale manufacturing capabilities was developed. This list is highly indicative, and further exploration is warranted; however, it does provide a first picture of potential collaborations. The numbers in the figure correspond to specific companies, which are listed per subsystem in the table below.

Figure 15: Indicative list of companies with manufacturing abilities



Source: Consultant

Table 5: Existing companies and capabilities

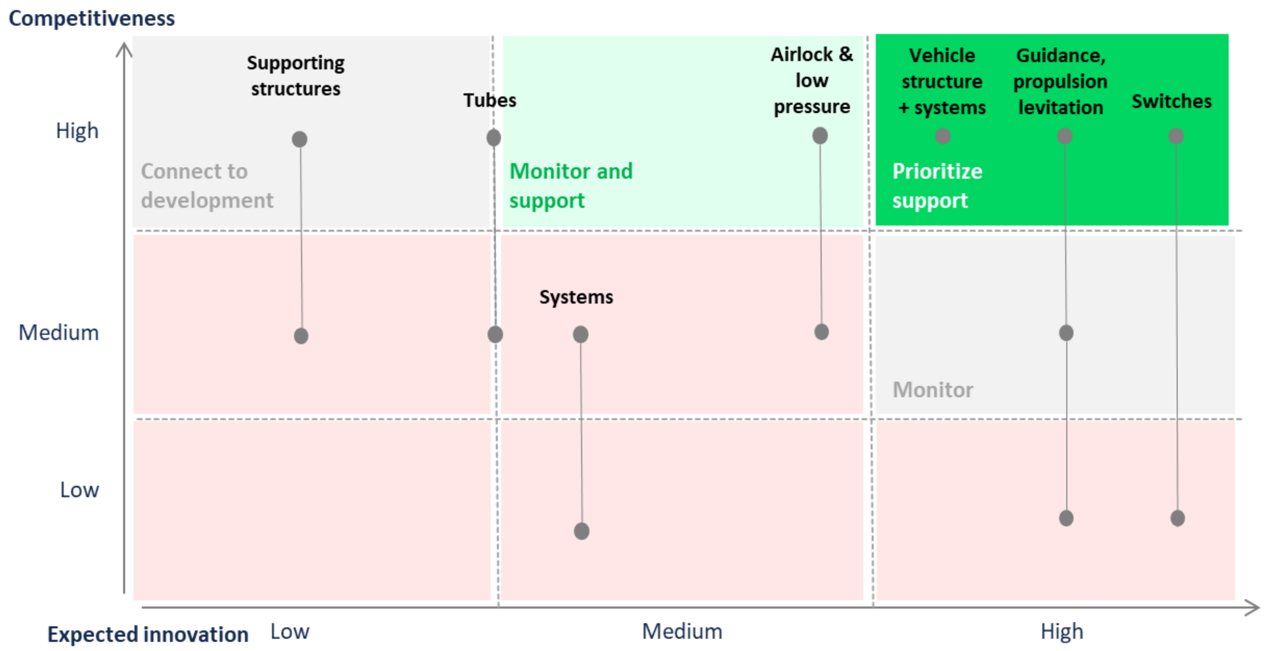
Component	Netherlands	Belgium	Luxembourg	Suppliers NRW
Pod	1 AirbusNL, 2 VDL 3 Hardt, 4 Airborne	5 Van Hool 6 Sabca 7 Sonaca, 8 ASCO, 9 Solvay, 10 Barco, 11 Moss Composites, 12 Materialise, 13 Exel Composites	15 BorgWarner Luxembourg, 16 IEE, 17 Foobot 18 Circuit Foil	19 Siemens TS & Waggonfabrik Uerdingen,
Propulsion	1 Hardt 2 Goudsmit Magnetics	3 Equans 4 Besix 5 Allard-Europe 6 Voestalpine Sadef 7 Victor Buyck	8 BorgWarner	9 Siemens Mobility GmbH (Krefeld)
Vacuum systems	1 Vacutech 2 Cluster surrounding ASML which uses vacuum technology, 3 Busch 6 Festo	4 Atlas Copco 5 Flowserve SIHI 6 Festo 7 Leybold	-	7 Leybold GmbH (Cologne) 4 Atlas Copco
Tube	1 Tata Steel 2 Feijen 3 Sif 4 Mercon	5 ArcelorMittal 6 Revimaxx, 7 Aperam, 8 Smulders 9 Victor Buyck	5 ArcelorMittal	10 Thyssenkrupp 11 Deutsche Doka 12 Schalungstechnik GmbH
Switch	1 Hardt	-	-	2 Voestalpine Railway Systems 3 Thyssenkrupp Infrastructure GmbH 4 Vossloh Cogifer GmbH
Systems	1Technolution (control) 2 Thales (signalling) 3 Beckhoff Automation	3 Beckhoff Automation	4 IEE	3 Beckhoff Automation GmbH & Co. KG (control), 5 Siemens AG, 6 Phoenix Contact GmbH & Co. KG (control)

Source: Consultant

Cluster development analysis summarized

When combining the analyses of expected innovation and competitiveness, the following picture emerges. and findings with concern to Hyperloop (sub)system development, cluster development and linkages to existing Benelux-NRW strengths in high-tech manufacturing and innovations can be summarized as follows:

Figure 16: Indicative mapping of expected innovation and competitiveness



Source: Consultant

- Currently, the main overlap between expected innovation and current competitiveness is apparent for the vehicle structure and systems. Belgium, Netherlands, Luxemburg and NRW all have existing capabilities with comparable existing technologies. Belgium is competitive in developing necessary materials, NRW has experience in rail infrastructure and rolling stock manufacturing, Luxembourg has a competitive automotive cluster and The Netherlands is competitive in development of pods and hosts potential production facilities.
- The switching technology is very dependent on current development by Hardt. Therefore, competitiveness differs significantly between countries. Due to the importance (setting the standard for switching could also result in setting the standards for rails and guidance), and expected innovation it could be useful to further connect potential suppliers when the technology takes the next step.
- Airlock and low pressure systems: The Netherlands has a highly competitive vacuum sector, partly surrounding the current ASML cluster. Other countries also have capabilities in this field. Innovation is related more to improvement of current systems, but it could still be worthwhile to connect existing players.
- Tubes: the Benelux + NRW are unlikely to have the scale to be a main tube supplier. However, there are chances for potential innovative techniques (reducing required steel with a skeleton from other materials) and precise construction / curves.
- Currently, the main companies involved are from the systems which have lower innovation. During the next steps involving suppliers and networks for the systems which require more innovation is important, also for cluster development.

3.5 Options for public sector action

Implementation drives future competitiveness

There is a reason why the Belgian port sector, the Dutch water management sector and the German car sector are highly competitive. And a major part of this reason is because it was implemented there. Antwerp invested in its ports, The Dutch invest in their fight against rising water, and the German invested in high quality roads If you don't build it, you will never get good at it, therefore, the chances of cluster development in the Benelux + NRW drastically increase when the countries decide to:

- Invest in at-scale test and demonstration system, common/open-access
- Invest in a first demonstration system internal or cross-border
- *and/or* make sure to support a wider regional effort for realization of such a system and carve out IP/position for Benelux-NRW manufacturing

Supporting innovative technology development

Connecting industries

- There are complementing industries in the Benelux +NRW , that could play a role in future Hyperloop development. Many of these are currently not involved. It is key that these complementing industries are connected before a proof of concept connection is developed in order for Benelux + NRW clusters to materialize.
- This study provides a starting point in identifying existing strengths, bringing this further requires an ongoing dialogue with the firms and other economic actors in the cluster. Although the public sector cannot be the exclusive driver of cluster policy, it can play a central role in convening cluster members and working with private-sector cluster organizations.
- This seems especially relevant for industries which are already mature (automotive and composite materials for pod development, and current vacuum industry for low pressure environment).

Invest in campus cluster development around one or several key PSL(s)

- Promote exchange and spillover between academic and industrial researchers by setting up facilities that allow them to work in close proximity to each other. This could include physical infrastructure (buildings specific test centres) and larger research programs and grant funding. The programs could also consist of connecting to.
- This seems especially relevant for technologies where current manufacturers currently manufacture products which are very different, for example the switching technology.
- A great example of such an initiative is the recently completed test track at the European Hyperloop Center, where multiple technology developers can collaborate to further develop key technologies and advance the Hyperloop industry collectively.

Figure 17: Test track at European Hyperloop Center

Source: European Hyperloop Center

Support supplier integration and development

Clusters are embedded in a local context because a network of suppliers develop specific capabilities and jointly invest in product development together with dominant parties in the supply chain. Currently there is a lack of supplier involvement for the more innovative technologies (the major partners are more focused on supporting structures, tubes, etc.) while many of the more innovative products are still made and developed in-house. To improve cluster development (and therefore local embeddedness)

- Monitor potential key IP and capabilities being developed by Benelux-NRW technology developers. Especially for the technologies
- Support ecosystems surrounding these technologies through funded alliances with public (-private) technology knowledge institutes and academia.
- Support ecosystems surrounding these technologies to develop, including process and equipment optimization of suppliers.
- This seems relevant for both technologies which still need to develop a lot, and technologies where current manufacturing capabilities are closer to desired products.

Nurturing technology developers, ensure they stay (i) connected, (ii) protected and (iii) ahead of the curve

- Require regional systems to include content by technology developers.

- Active promotion of domestic built Hyperloop systems and ecosystems around key technologies globally, target and support partnerships where other Hyperloop developers are moving ahead of the curve (PSLs can learn and improve by cooperating and competing in those markets).
- Gradually increase standards and harmonization requirements, reduce protective measures to enhance competitiveness and shake off any inefficiencies (a good example for this strategy is electric vehicle industrial policies where standards were gradually increased where protective measures were gradually decreased).

Potential constraints, challenges

- **Limited enthusiasm:** in Luxembourg and NRW Hyperloop is not a top of mind development. In Belgium more organizations have been historically involved, but during conversations with private sector parties limited there was little to no current action. In Germany the history of the accident at the Transrapid test system leads to hesitations around the introduction of new (similar) transport technology.
- **Acquisition of key IP**: Creating new clusters deliberately through public policy is challenging. Instead, policymakers and practitioners should focus on fostering and sustaining the economic conditions conducive to the emergence of new clusters. This entails supporting activities such as knowledge creation, entrepreneurship, the establishment of new firms, and access to capital. Cluster policy does not involve favouring certain industries over others or excluding them. By cultivating an ecosystem that incorporates these elements, it becomes harder to simply “move” the primary intellectual property (IP) to another location.
- **Legal constraints:** the legal requirements present in the various countries pertaining to safety licenses and operations permits may introduce substantial lead times into the development and implementation process.

4. Possible proof of concept connections

4.1 Approach

In this chapter, the proof of concept connections with the highest feasibility are determined.

- Firstly, a longlist of connections based on previous research is illustrated.
- Secondly, a shortlist is sieved out of the longlist. This is based on origin-destination matrices of the locations in the longlist.
- Thirdly, the shortlist of connections has been scored with a multi criteria analysis based on the concept of Broad Prosperity to discern between the connections.
- Subsequently concluding remarks, recommendations for next steps and upcoming roadblocks are discussed.

4.2 Longlist based on current mapping and previous research

A longlist has been created with 18 corridors in which Hyperloop could be feasible. All corridors are aggregated and put on a map as an input to an internal workshop with stakeholders. During this workshop several more corridors were added. The resulting longlist is included in Table 5.[6]

Table 6: Longlist of corridors

Longlist connections	
Almere-Lelystad	Eindhoven-Brussels
Amersfoort-Arnhem	Eindhoven-Düsseldorf
Amsterdam-Berlin	Eindhoven-Eindhoven airport
Amsterdam-Eindhoven	*Euroloop* (a number of medium to large cities in Belgium, the Netherlands and Germany)
Amsterdam-Frankfurt	Lelystad-Schiphol airport
Amsterdam-Groningen	Lelystad-Zwolle
Amsterdam-(Leiden-The Hague)-Rotterdam-Antwerp-Brussels	Luxembourg - Brussels
Brussels-Paris	Maastricht-Liège-Aachen
Düsseldorf-Berlin	Utrecht-Eindhoven

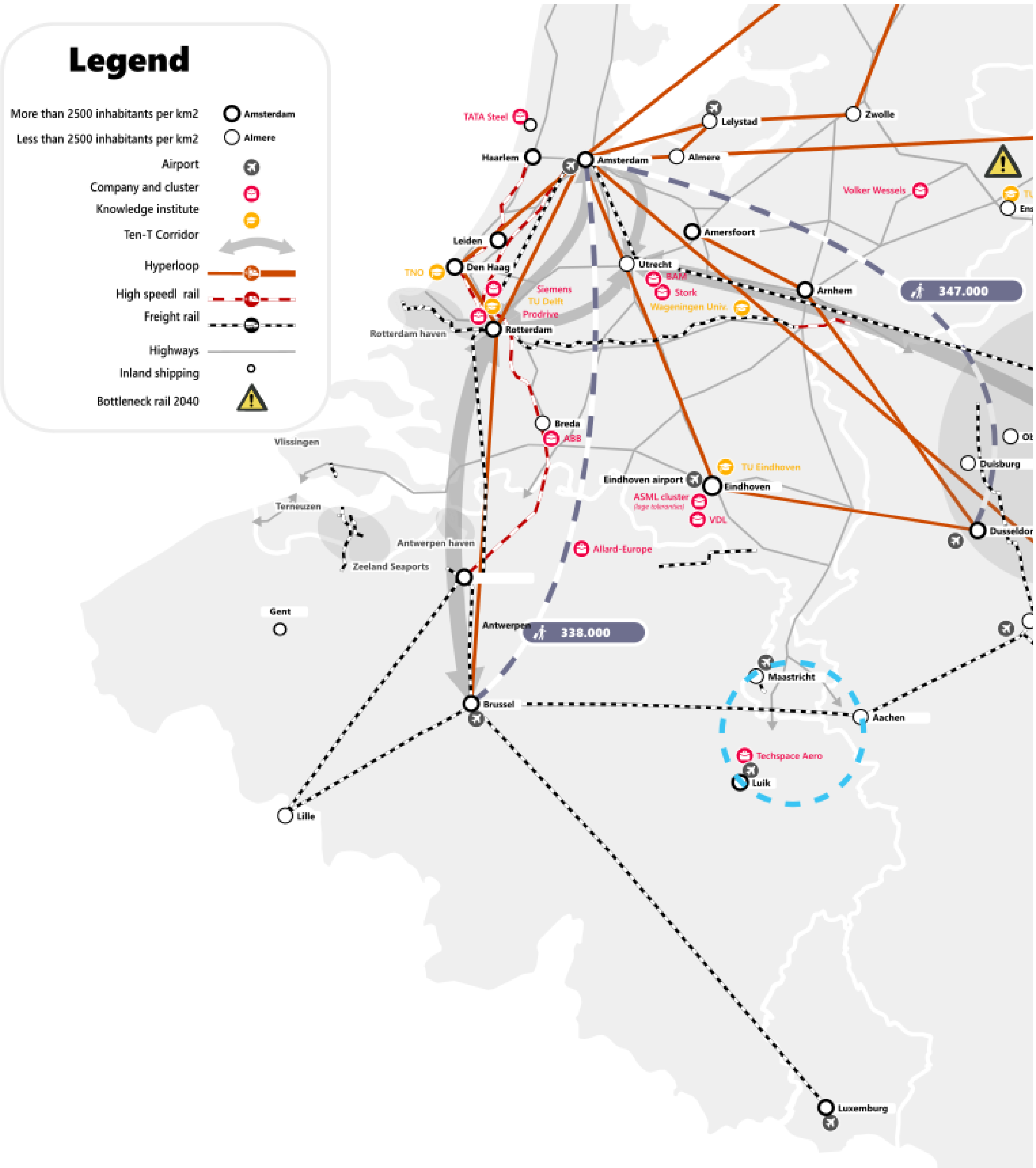
Source: Consultant

Because of the scope of this study cross-border connections are preferred. Therefore, the longlist has been cut down to only include cross-border connections.

A visual representation of the longlist and all relevant information to determine the longlist can be seen in Figure 12. Factors include but are not limited to the vicinity of large agglomerations, universities, ten-t corridors, airports and relevant knowledge and production clusters.

[6] This table lists all the corridors proposed for the longlist. The longlist is based on earlier studies. The studies used are: Schiphol & Hardt, Compacte metropool, The current state of the Hyperloop, Cargo Hyperloop Holland, Hyperloop: a Crossroads perspective, Hardt Amsterdam-Frankfurt, Hyperconnected Europe Hardt.

Figure 18: Overview of the studied area with relevant infrastructure and movements



Source: Consultant

4.3 Shortlist based on transport potential

All the locations present in the longlist connections are examined with regards to the number of origin-destination trips made. This is done for passengers, as well as for freight. A list of all data sources investigated can be found in the appendix.

- The passenger data is based on IntraPlan: Cross border data and prognoses for passenger transport by car, train, air and (long) bus lines.

- The freight data is based on Basgoed: A strategic freight transport model to forecast road, rail and inland shipping. Basgoed aims to map the effects of economic developments and policy measures on freight transport in, to, and from the Netherlands.

It is helpful to visualise the origin-destination matrices and the largest passenger and freight connections. To get a grasp on how the passenger streams differ from each other, we visualised them in charts that show the flows between origins and destinations. Due to the sensitivity of the data, the actual numbers themselves are not shown. To keep the graphs concise, there is a cutoff (at a specific number of total trips per year) below which connections are not shown.

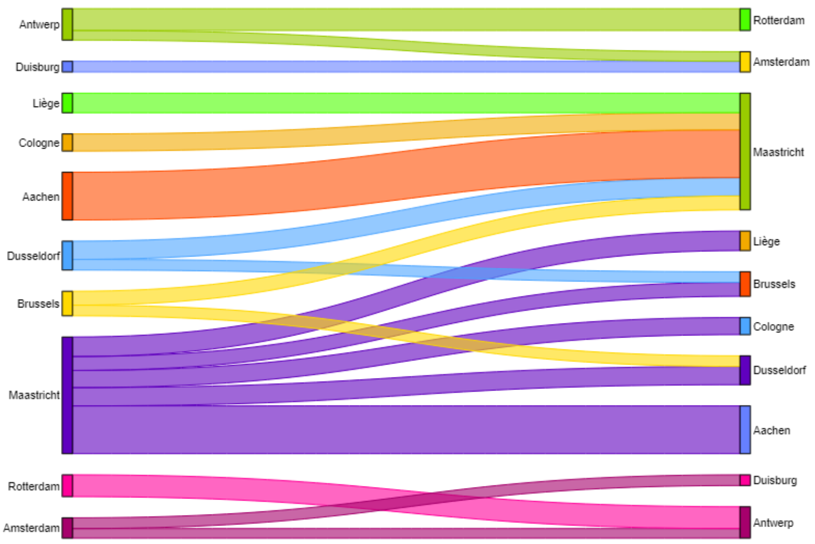
4.3.1 Passenger transport

For passenger transport, this results in the figures below.

Figure 13 shows the total number of trips per year between the origin (left) and the destination (right). This includes all modalities. Note that the origin-destination matrices are symmetric. That is, the number of trips from origin A to destination B is the same as the number of trips from origin B to destination A few connections immediately stand out, such as the triangle Maastricht – Aachen – Liège. Note that even though Luxembourg is included in the longlist, it does not show up here because the total amount of trips in the IntraPlan model (which only shows trips to and from the Netherlands) to Luxembourg is limited.

The IntraPlan numbers are based on zone to zone movements, these zones are sometimes quite large. If zones are bordering, this can give a skewed image because car trips right over the border of the zone are also counted as a trip but might not be suitable to replace with Hyperloop trips.

Figure 19: Total trips/year from origin city zone (left) to destination city zone (right), all modalities



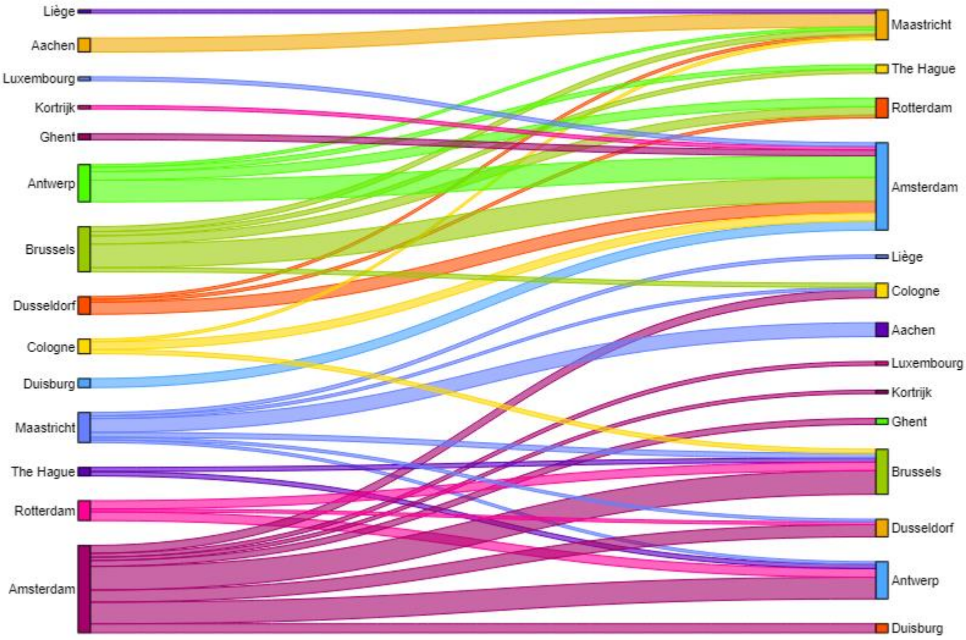
Source: Consultant, underlying data based on IntraPlan

Figure 14 shows the total number of trips, excluding car trips. Because the number of trips made by car is large, this has a large influence on the distribution of passenger streams. Next to the aforementioned triangle, a second connection emerges out of the data: the axis Amsterdam –

Rotterdam – Antwerp - Brussels. Together with the triangle Maastricht – Aachen – Liège, this then becomes the shortlist of proof of concept connections.

Modalities included are rain, bus and air. The figure is based on data from IntraPlan. A cutoff is used, above which connections are not shown. Because of the sensitivity of the source data, the actual cutoff number is not mentioned in this report. Note that especially outside of the Netherlands the zones have a low level of detail.

Figure 20: Total trips/year from origin city zone (left) to destination city zone (right), excl. car



Source: Consultant, underlying data based on IntraPlan

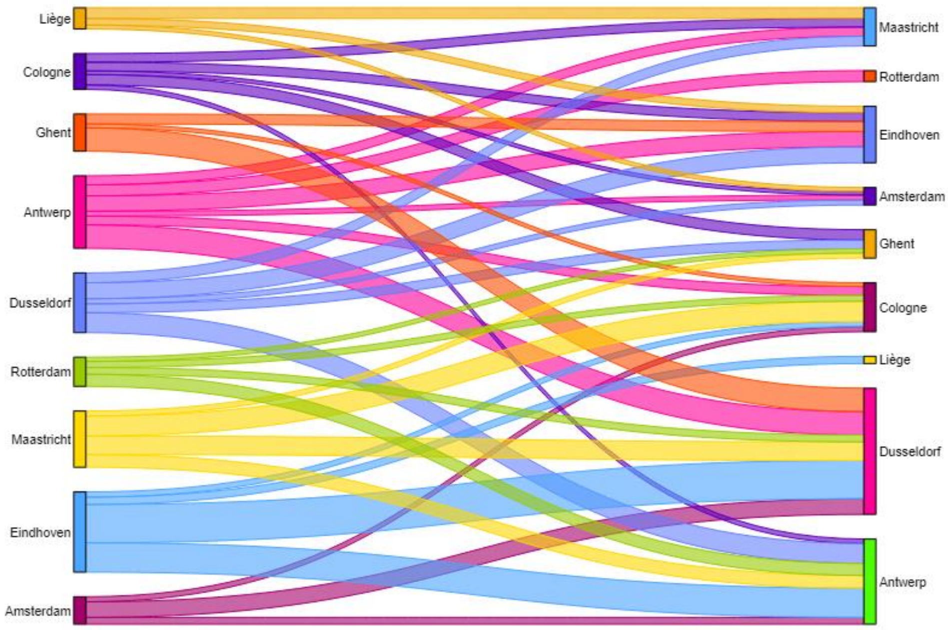
4.3.2 Freight transport

For freight transport, the same longlist of connections is used to visualise the streams of goods between these locations. Hyperloop might be used for freight and some advantages may be used which cannot be used for passenger transport. For example, goods may be able to undergo higher loads of acceleration. Also, the modal split for freight largely depends on costs and less so on factors as comfort and experience as is the case for passenger transport. Because of the relatively high costs of using the Hyperloop as modality, the analysis here is limited to high value goods. Specifically, only commodity group 11 (machinery and equipment) was considered.

In future studies, other types of cargo could be considered such as medicine or flowers. Due to the relatively crude categorisation of the BasGoed model, these were not taken into account in this study.

Similarly to the passenger transport, the connections are visualised in Figure 15. Some large attraction or production zones are present, but no clear conclusion can be drawn from the relations present. Multiple connections of similar size are present, but none of those are connections that actually stand out. Instead, freight movement could be used to help the business case for passenger transport by Hyperloop.

Figure 21: Transported freight tonnes/year over roads from origin (left) to destination (right).



Source: Consultant

Only freight of commodity type 11 (machinery and equipment) is show. The figure is based on data from BasGoed and includes both container and non-container transport. The data only contains connections to and from the Netherlands. This means that connections between countries other than the Netherlands and connections within the Netherlands do not show.

A cut-off is used, above which connections are not shown not keep the graph readable. Because of the sensitivity of the source data, the actual cutoff number is not mentioned in this report.

4.4 Multi criteria analysis based on broad prosperity

A multi criteria analysis has been done to discern between the connections based on the concept of Broad Prosperity (sometimes also called wellbeing economy). Within the concept of Broad Prosperity five goals are distinguished, as shown in Figure 16.

The goals give a nuanced view of the effects implementing Hyperloop has. Next to the effects of the Hyperloop on the people living nearby future Hyperloop locations (here and now), the effects on people living somewhere else (not here) and the effect on future generations (not now) are discussed in this paragraph when deemed relevant. The goals and a short description on the relation with the Hyperloop is shown in the table below.

It should be noted that the multi criteria analysis is done on the shortlist. Since that means the transport potential has already been taken into account, it is not taken into account again in the MCA. It is, however, used as input to the cost effectiveness calculation.

Figure 22: Five goals of broad Prosperity

Table 2: Broad Prosperity goals, effect of the Hyperloop on these goals.

Goal	Criteria	How does the Hyperloop affect the goal?
Health	How are people affected by the Hyperloop with regards to health?	The Hyperloop may reduce the road and air traffic and, thus, reduces the unhealthy emissions that are caused by road and air transport. Conversely, mining of rare earth minerals and the production of large amounts of steel for building the Hyperloop can have a negative effect on people living nearby these mining and steel industries, immediately or in the future. Whilst the majority of the positive health effects are mainly for people living in the direct environment of future Hyperloop locations (here and now), the majority of the negative health effects are felt elsewhere (not here). The health criterion is not distinctive for the different connections. Overall direction of effect: neutral (both positive and negative arguments)
Social inclusion	How does the Hyperloop increase or decrease social inclusivity?	The social inclusiveness of the Hyperloop is limited. At first, it is an expensive modality for the user. The Hyperloop concept has positive effects for the social classes with high income who do not live nearby the Hyperloop itself. However, Hyperloop can connect areas with each other that are currently not well connected, ensuring better accessibility of places with affordable housing to jobs and social amenities. This principle of improving accessibility where it is lacking most, could potentially also cool down the housing prices in places with lots of economic activity and a higher diversity transport options. This criterion is not distinctive for the different connections. Overall direction of effect: negative. The effects of the Hyperloop on social inclusion are negative because it would increase social inequality.
Sustainability	How sustainable is the Hyperloop?	A Hyperloop has positive sustainability effects, such as reduced emissions by replacement of air traffic/airplanes. It may replace passenger and cargo trips by road as well. The replacement of air and road traffic may improve modal shift towards sustainable modes. The criterion that air traffic may be substituted by Hyperloop technology is taken into account explicitly in the scoring below. Because the Hyperloop is electric, it has the potential to operate without emissions if the electricity is generated without emissions. On the other hand, building and maintaining Hyperloop constructions is capital intensive and asks for vast amounts of steel production, concrete production, and the mining of rare earth minerals. This has negative impact on environment, but the

		impact on climate change per km pales by the operational emissions from aviation. Next to that, the rare earth minerals mined for the Hyperloop would overlap with the ones needed for the energy transition. Whilst the majority of the positive sustainability effects are mainly for people living in the direct environment of future Hyperloop locations (here and now), the majority of the negative health effects will happen somewhere else (not here) and to future generations (not now). The scores on the connections are distinguished on the fact whether or not air traffic can be replaced. Overall direction of effect: neutral (both positive and negative arguments)
Quality of the living environment	What effect does the Hyperloop have on the living environment?	The Hyperloop concept brings new possibilities in the design of the public space and densification of urban areas. Noise pollution caused by a Hyperloop is much lower than for air (and road) traffic. A side effect can be the increase of road traffic in the neighbourhoods of future Hyperloop stations. People and trucks still need to make the first- and last mile transportation towards the Hyperloop locations. This criterion is not distinctive for the different connections. Overall direction of effect: The effects of Hyperloop on the quality of the living environment are positive.
Cost effectiveness	How does the Hyperloop help with economic vitality?	Cost effectiveness goes up when more people use the Hyperloop and when the full speed of Hyperloop is used. To achieve the full speed a certain length of the tube is desired, but controversially, the costs go up when the connection is longer.

Source: Consultant

For most of the goals, there is no notable difference between the scores of the connections.

Two goals where the connections can be discerned more clearly are Sustainability and Economic vitality. With regards to Sustainability, a connection is given a plus (+) if air traffic can be replaced. This is true for the connection Amsterdam – Brussels.

With regards to Economic vitality, a scoring is based on the predicted number of people using the Hyperloop. For the axis Amsterdam – Rotterdam – Antwerp – Brussels, also intermediate stops are included in the analysis. That is: in the connection Amsterdam – Antwerp, people travelling from Amsterdam as well as people travelling from Rotterdam are included. A longer Hyperloop connection costs more money to build, so it is included as a negative factor.

Lastly, since one of the main selling points of the Hyperloop is its high speed, the percentage of time at which it can operate on full speed is taken into account. For shorter trips, a relatively large amount of time will be spent accelerating and decelerating. The key figure for cost-effectiveness is then calculated as follows, after which it is z-scored and rounded to the nearest integer.

$$EV = \frac{\#people}{distance} time_{full\ speed}$$

The MCA gives the following results.

Table 3. Results of multi criteria analysis on proof of concept connections

Criterion / ***Route***	Health	Social inclusiveness	Sustainability	Quality of living environment	Cost effectiveness	Total
Aachen – Maastricht	0	-	0	+	+	+
Maastricht – Liège	0	-	0	+	-	-
Aachen – Liège	0	-	0	+	-	-
Amsterdam – Antwerp	0	-	0	+	0	0
Amsterdam – Brussels	0	-	+	+	+	++
Rotterdam – Antwerp	0	-	0	+	-	-
Rotterdam - Brussel	0	-	0	+	0	0

Source: Consultant

Based on the MCA the connection Amsterdam – Brussel has the highest score because a lot of people are predicted to use it, it may operate at full speed most of the time, and it has the potential to replace flights.

4.5 Conclusions: Where to search for a first PoC?

Based only on transport potential, it is difficult to point to a specific PoC connection where it could help solve (capacity) problems. One should not expect a Hyperloop connection of a few kilometres to solve the current capacity problems. The transport potential on short-distance cross-border relations are relatively low and, additionally, the benefits of the Hyperloop are difficult to utilise on short distances. Analysis in the transport potential did not result in a clear best location for a first Hyperloop connection. The choice for location of a PoC connection should therefore mainly be based on the potential for industrial cluster development and possible symbolical value for a specific region.

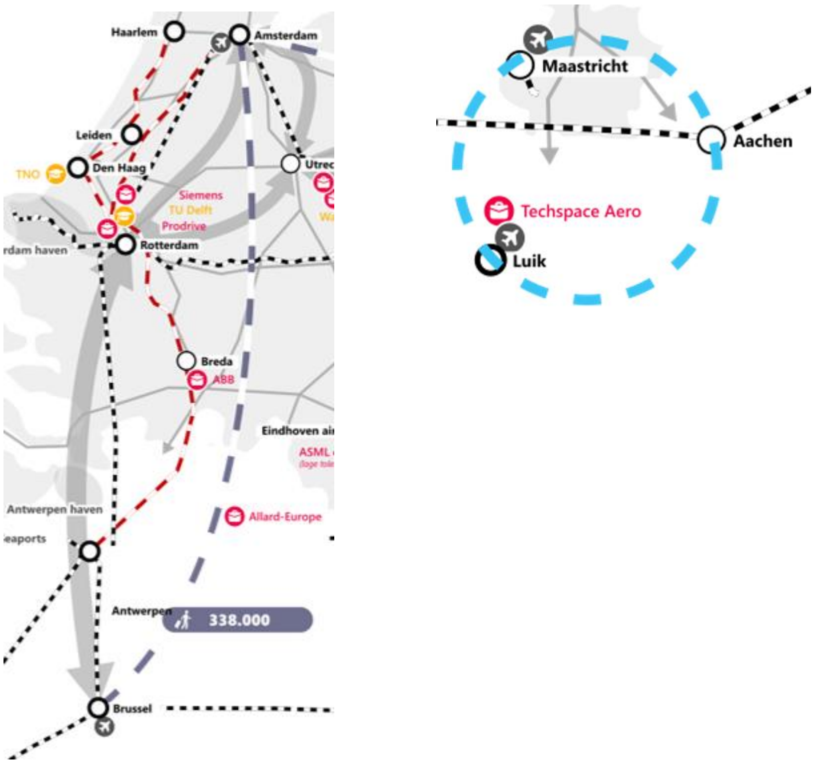
Based on the BasGoed model a lot of road traffic is visible within the study area but cannot be reduced easily with the Hyperloop. Therefore, it is advised to focus on the potential to reduce air traffic rather than road traffic. Based on the calculations on the cargo potential there is no reason to invest in a strong(er) cargo corridor by means of Hyperloop technology.

The Hyperloop is most promising for passenger transport rather than transportation of cargo. The system could serve passenger transport and transportation of cargo with its remaining capacity to improve its business case. Because of its high capacity, possibly both could be served. For that reason, a connection with the port of Rotterdam could be useful.

For the transportation of passengers two connections (see Figure 17) are suggested:

1. Amsterdam – Rotterdam - Antwerp – Brussels: This connection is promising, because it has the potential to substitute short-haul flights. Because of the longer length of the connection, it utilizes the full-speed advantage of Hyperloop. However, high-capacity rail connections are already in place on this trajectory. An important point is to make sure Hyperloop supports the current public transport network, instead of competing with it.
2. Maastricht – Aachen – Liège: This connects multiple cities and can be seen as a first step to a Hyperloop network. Between these cities, little to no current public transport infrastructure exists and travel time by car is considerably shorter than by public transport. This is especially the case for the connection between Maastricht and Liège.

Figure 23: Suggested zones for PoC connections.



In general, Hyperloop is a promising concept on connections where no sufficient rail connection exists or as replacement of air traffic. Because of its high capacity, frequency and speed it could have a significant impact on travel patterns and demand for passengers and high-value cargo. The biggest potential that utilizes most of the hyperloop capabilities is in a large hyperloop network with long links between densely populated areas and areas of interest, where passengers and freight seamlessly transfer. As mentioned above, the potential for short connections is limited. The larger the network, the better it can be utilized.

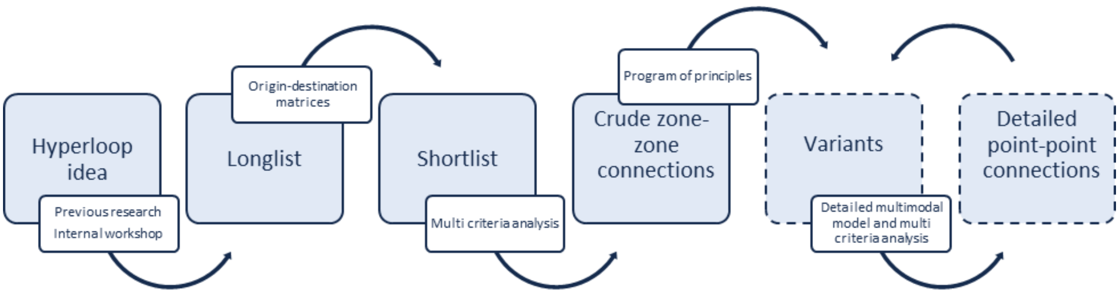
4.6 Challenges in further research to decide PoC location

The studies done up till now are based on the existing origin-destination matrices. Because this is a first study, the zones included in the study are of a low level of detail. This results in crude zone-zone proof of concept connections.

The next steps in the process to come to a detailed point-point connection is to carry out a variant analysis in which a few variants are investigated with a more detailed multimodal model. These variants can be scored with a multi criteria analysis as well. This process can be iterated a few times to come to the best proof of concept connection. The process up till now, and the next steps are presented visually in the figure below. In further steps, the key findings up till now should be included in the design process. That is, PoC connections should try to supplement the current network as much as possible and have the possibility to grow into a larger network with long links between densely populated areas and important areas of interest such as airports.

The steps yet to follow are indicated with dashed edges.

Figure 24: Steps to define detailed point-point connections



Source: Consultant

During the assessment of the transport value for the Hyperloop, a number of challenges ahead were identified.

The most significant ones are as follows:

- Because a Hyperloop is a new modality that assumes high speeds and high capacity, it would have significant effects on travel patterns and transport demand. Current multimodal models are not very well suited to accurately predict the effects of changes this significant because they are too far from the current reality on which these models are calibrated. Therefore, developing a multimodal model that can include such large changes is essential. This model can be used to investigate Hyperloop, but also any other modality with both high speeds and high capacity. An incremental approach where Hyperloop technology is introduced gradually could provide an answer to this problem, because models could regularly be calibrated.
- The challenge above also holds for the first and last mile transport of goods. Very high capacity connections also require very high capacity loading and unloading docks.
- Data availability on cross-border travel is limited. This problem has two aspects. On the one hand, the models that are used to predict travel are often developed with a heavy emphasis on one country. This results in accurate results within that country, but also more and more crude results and larger zones the farther one moves from the country of origin. On the other hand,

organisations that do have access to this data hesitant to share it because of a variety of reasons such as privacy, political sensitivity or out of fear to lose competitive advantage.

- Information on air travel is limited both for passenger and freight transport. Often airports list how many flights they carry out yearly but not how many passengers or freight are on board, and the destinations of the flights. For passenger transport, an estimate can be made by looking at the frequency at which a route is operated, and which type of plane is used. However, this is time consuming and still only an estimate. In future work, it should be considered to also include airports in the decision process.
- Consider that the freight flows for which hyperloop has added value will make the connection to the Hyperloop network themselves. To guarantee this interconnectivity, it is crucial that the Hyperloop network connects the most important airports. The amount of freight that will be transported by Hyperloop, considering this development, is very hard to predict. Include (air)ports in future studies to make sure that information will be retrieved.

To accurately predict the transport potential of a Hyperloop connection (or any modality with both high speed and high capacity), it is paramount that these challenges are overcome.

5. Benelux-NRW strategic perspectives

5.1 Potential approaches and outcomes

We have reviewed the current state of play and multiple plausible development trajectories of Hyperloop from here, as well as potential Benelux public sector actions related to cluster development and (cross-border) proof-of-concept and connectivity realization.

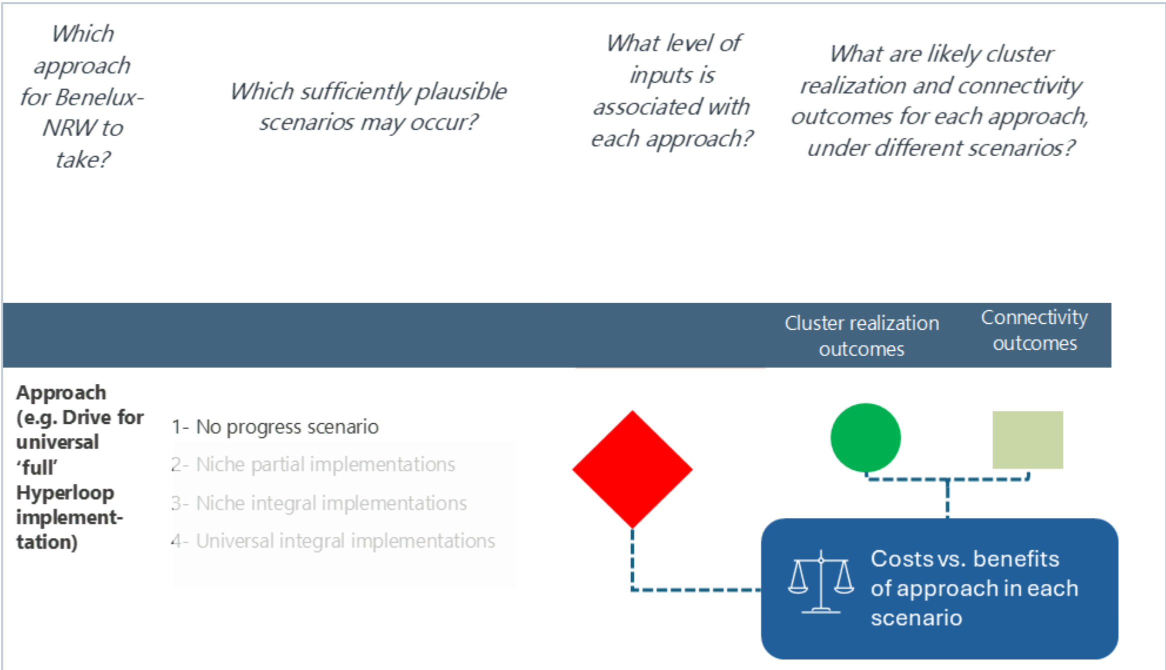
Three distinct strategic perspectives to guide and inspire decision-making

Based on this, we bring together three distinct strategic perspectives together. They are distinctive in terms of proactive or reactive public sector postures as well as deliberate steering of Hyperloop development towards integral or towards (initially) partial implementation.

These perspectives serve to guide further discussion and decision-making by Benelux and NRW government actors concerning potential approaches and expected outcomes:

- *Drive for universal 'full' Hyperloop implementation* based on robust public sector championing of integrated Hyperloop development within the Benelux-NRW;
- *Facilitate gradual development and foster specialization* through implementing Hyperloop sub-systems into existing transportation systems within the Benelux-NRW and into full Hyperloop systems elsewhere; and
- *Let the market direct and decide*, while facilitating the development of technology specialists with a strong position in global supply chains for Hyperloop systems.

Figure 25: Framework for resulting analysis of approaches



Source: Consultant

For each approach we describe implied optimal public sector actions, as well as potential and plausible outcomes under different plausible scenarios for Hyperloop development:

- Long-term economic value-added from innovative Hyperloop manufacturing
- Decongesting Benelux transport networks and creating more integrated and more optimized agglomerations (direct and indirect economic gains

Long-term economic value-added from innovative Hyperloop manufacturing

In academic literature on economic growth, the contribution of technology innovations to productivity growth is estimated to range from 33% to 66%.

This is confirmed in a simplified, worked example based on 2018 OECD-wide averages below. The implied 'residual' contribution of technology innovations (and other factors including in particular labour growth which is however assumed modest to negligible in this example) is shown to be just under two-thirds of total GDP growth.

Time and again, research highlights that the dominant driver of long-term economic growth is technology innovation, producing gradual growth in most cases and – incidentally – sustained periods of above-average growth due to the innovation of new General Purpose Technologies GPTs) which enable a wide range of applications and spillovers.

Table 7: Innovation and economic growth (simplified illustration)

			~OECD 2018 average	Derived	Implied/ residual	*Relative share contributions to GDP growth*
GDP growth	1	Change y/o/y	2.5%			
Gross Fixed Capital Formation (GFCF)	2	Change y/o/y	3%			
	3	Contribution to GDP growth		1% (2) [7]		*40%*
Total Factor Productivity (TFP) 'residual' related to technology innovation	4	Contribution to GDP growth			1.5% (1-3)	*60%*

Source: Consultant

In accordance with this, and although a fully developed Hyperloop technology would not be a general purpose technology, the technology innovation related to successful achievement of first-of-a-kind Hyperloop implementation would have substantial potency as a driver of GDP growth across the countries involved and affected.

[7] Based on the one-third rule concerning the relation between changes in capital and changes in (labor) productivity

The benefit of innovation and spillovers would accrue more strongly to those countries spearheading the innovation as measures like IP protection would slow-down others from copying the innovation and enjoying both the direct benefits as well as the spillovers from the innovation.

Decongesting Benelux transport networks and creating more integrated and more optimized agglomerations

More directly, and somewhat separate from which country and technology developer 'owns' the eventual Hyperloop technology, the implementation of Hyperloop connections would enhance the efficient functioning of transport networks and urban regional economies. For project-specific implementations, this could be calculated as economic gains related to travel time gains, vehicle operating cost savings, avoided investments and agglomeration economies of scale.

In more elaborate follow-up research, these outcomes might be quantified for specific innovation and/or project scenarios.

This exploration of strategic perspectives includes expert judgment on the potential significance of outcomes.

5.2 Drive for universal 'full' Hyperloop implementation

This approach concerns a proactive public sector stance towards full Hyperloop implementation.

In more detail it can be characterised as follows:

- Benelux-NRW (public sector generally and/or specifically designated government agencies or special purpose agencies) go '*all-in*', providing funding and facilitating the site and/or right-of-way for the first at-scale test system(s) and first operational system (full link or proof of concept) within Benelux-NRW borders.
- Benelux-NRW implement a concerted effort to advance the concept, standards and planning of a European Hyperloop network;
- Benelux-NRW provide broad-based incentives and grant programs to aid Leading Technology Developers (LTDs) to achieve scale and optimize respective supply chains and support supply chain partners as testing and development progresses; and
- Encouraging regions and cities to cooperate on a cluster strategy supporting 'campus' development for/around selected LTD(s).

The table below summarizes Benelux-NRW inputs as well as, for different scenarios identified as plausible, the potential outcomes.

Table 8: Inputs, outcomes and scenarios: drive for full Hyperloop implementation

Level of Benelux-NRW (funded) inputs implied	This approach entails substantial commitment of funding and policy effort and actions up-front. It also requires longer-term vision and willingness to invest in the viability gaps likely associated with the roll-out. operation and maintenance of fully functioning Hyperloop links including (at least for the first implementation(s)) in the Benelux-NRW itself.	
	◆◆◆◆◆◆	
(Scenarios)	*Cluster realization outcomes*	*Connectivity outcomes*
1- No progress scenario	• Initial manufacturing development does not result in new supply chains or cluster development; • Likely some spillover from innovations in specific subsystems to other industries and capabilities.	• No connectivity impacts
Benelux-NRW economic value creation implied	●	-
2- Niche partial implementations	• Some technology component(s) developed by early Hyperloop pioneers commercialized into existing transport systems and/or in one or several new links; • 'Niche' scale of implementation insufficient to result in substantial new supply chains or cluster development, but temporary activities may create a similar footprint (similar e.g. to the TransRapid test site); • Possibly spillover from innovations in specific subsystems to other industries and capabilities.	• Incremental gains from connectivity improvements, early realization of gains within Benelux-NRW.
Benelux-NRW economic value creation implied	●●	■■
3- Niche integral implementations	• One or several full Hyperloop implementations, if located in the Benelux-NRW offer temporary dominance to specific LTD(s) and Hyperloop operating specialist(s); • 'Niche' scale of implementation insufficient to result in substantial new supply chains or cluster development, but temporary activities may create a similar footprint (similar e.g. to the TransRapid test site);	• (Early) gains from connectivity improvements of introduction of full Hyperloop on specific niche corridor(s).

	• Likely spillover from innovations in specific subsystems to other industries and capabilities.	
Benelux-NRW economic value creation implied	●●●	■■■
4- Universal integral implementations	• Early lead from proof-of-concept and experiences by Benelux-NRW LTD(s) offer sustained first-mover advantage; • Substantial chance of new supply chains and cluster development around one or several LTD champion(s); • Likely spillover from innovations in specific subsystems to other industries and capabilities.	• Gains from connectivity improvements of introduction of full Hyperloop on specific niche corridor(s).
Benelux-NRW economic value creation implied	●●●●●●	■■■

Source: Consultant

5.3 Facilitate gradual development, choose specialization

This approach concerns a more deliberate public sector stance assuming and facilitating gradual Hyperloop implementation. It implies more emphasis on specialization in manufacturing of (partial) Hyperloop technology, early on.

In more detail this approach could be characterised as follows:

- Benelux-NRW (public sector generally and/or specifically designated government agencies or special purpose agencies) encourage and facilitate testing and first 'proof' implementation of partial Hyperloop technology. This involves either retrofitting existing transport systems or creating new alignments) in cooperation with EU partners and large transit operator partners;
- Benelux-NRW promote continued implementation of Hyperloop technology (sub)systems developed and proofed by LTD(s) into selected transport corridors within the Benelux-NRW area;
- Benelux NRW undertake a joint support program for key LTD(s) in terms of localization, supply chain optimization and export promotion;
- Benelux-NRW champion standardization and harmonization of Hyperloop technology regionally and globally with a focus on incorporating Benelux-NRW 'homegrown' solutions and IP of relevant Hyperloop technology parts (either for retrofitting existing transport systems or for new Hyperloop systems);
- Benelux-NRW promote EU support for growing a continental Hyperloop market and network.

The table below summarizes Benelux-NRW inputs as well as, for different scenarios identified as plausible, the potential outcomes.

Table 9: Inputs, outcomes and scenarios: facilitate gradual development, choose specialization

Level of Benelux-NRW (funded) inputs implied	This approach entails commitment and where needed funding support to proof-of-concept implementation of partial Hyperloop technology and for successful development of proven-successful LTD(s). If retrofitting of existing transport systems, Benelux-NRW will likely need to incentivize existing infrastructure and transportation agencies . It furthermore requires strategic and proactive positioning of successful Hyperloop technology parts developed by LTD(s) for inclusion in Hyperloop development regionally and globally.	
	◆◆◆◆	
(Scenarios)	*Cluster realization outcomes*	*Connectivity outcomes*
1- No progress scenario	• Initial manufacturing development does not result in new supply chains or cluster development; • Likely some spillover from innovations in specific subsystems to other industries and capabilities.	• No connectivity impacts
Benelux-NRW economic value creation implied	●	-
2- Niche partial implementations	• Hyperloop technology parts developed and proofed by LTD(s) commercialized into existing transport systems and/or in one or several new links; • Early focus on developing partial Hyperloop solutions increases the likelihood of LTD(s) success in all of the limited number of niche implementations; • Early focus on developing partial Hyperloop solutions increases the likelihood of spillover from innovations in specific subsystems to other industries and capabilities.	• Limited incremental gains from connectivity improvements, potentially faster realization of gains due to focus on partial implementations.
Benelux-NRW economic value creation implied	●●●	■
3- Niche integral implementations	• One or several full Hyperloop implementations, if located in the Benelux-NRW are likely to include substantial inputs from specific LTD(s);	• Gains from connectivity improvements of introduction of full Hyperloop on specific niche corridor(s).

	• Integral nature of implementations means LTD(s) with a strong position in Hyperloop technology parts are less likely to dominate the overall supply chain; • Possible spillover from innovations in specific subsystems to other industries and capabilities.	
Benelux-NRW economic value creation implied	●●	■■
4- Universal integral implementations	• Successful LTD(s) in Hyperloop technology parts will for some time be able to set the standard; • The early dominance of larger players from outside the Benelux-NRW will lower the chances of a long-term position of LTD(s) in the supply chains as they are less in control of the direction of technology development; • Likely spillover from innovations in specific subsystems to other industries and capabilities.	• Gains from connectivity improvements of introduction of full Hyperloop on specific niche corridor(s).
Benelux-NRW economic value creation implied	●●●●	■■■

Source: Consultant

5.4 Let the market direct and decide

This approach concerns a market-driven process of development of Hyperloop technology.

In more detail this approach could be characterised as follows:

- Benelux-NRW (public sector generally and/or specifically designated government agencies or special purpose agencies) champion standardization and harmonization of Hyperloop technology regionally and globally without specific bias or preference to individual suppliers;
- Benelux-NRW facilitate development of at-scale, *open-access* test centre and first operational system by proactively arranging site, ROW requirements;
- Benelux-NRW actively promote public-private dialogue on requirements for integration with existing transport corridors and infrastructures; and
- Towards and following achievement of across-the-board TRL9 for (full) Hyperloop technology, Benelux-NRW ensure integration of Hyperloop as a transport mode into regular infrastructure and transport investment planning and implementation mechanisms.

Table 10: Inputs, outcomes and scenarios: let the market direct and decide

Level of Benelux-NRW (funded) inputs implied	This approach entails facilitating and supporting the development of Hyperloop technology in general, while remaining impartial to specific LTD(s) or technology solutions. It shifts the focus to private sector initiative and financing of development and implementation, while policy actions continue to target harmonization, integration with existing transport systems and normalization of Hyperloop as a 'generic' transport modality.	
	◆◆	
(Scenarios)	*Cluster realization outcomes*	*Connectivity outcomes*
1- No progress scenario	• No significant supply chains or cluster development; • No significant spillover from innovations in specific subsystems to other industries and capabilities.	• No connectivity impacts
Benelux-NRW economic value creation implied	-	-
2- Niche partial implementations	• Limited likelihood of selected LTD(s) being able to obtain a position in a Hyperloop supply chain for 'partial' implementations dominated by technology developers and implementing companies originating from larger markets within and outside the EU; • Limited likelihood of cluster development for 'original' LTD(s), best opportunities for existing Benelux-NRW manufacturing leaders to include Hyperloop component(s) in their portfolios.	• Limited incremental gains from connectivity improvements, potentially faster realization of gains due to focus on partial implementations.
Benelux-NRW economic value creation implied	●●	■
3- Niche integral implementations	• Small to negligible likelihood of Benelux-NRW LTD(s) being able to obtain a position in a Hyperloop supply chain for 'full' implementations dominated by technology developers and implementing companies originating from larger markets within and outside the EU; • Limited likelihood of cluster development for 'original' LTD(s), best	• Gains from connectivity improvements of introduction of full Hyperloop on specific niche corridor(s).

	opportunities for existing Benelux-NRW manufacturing leaders to include Hyperloop component(s) in their portfolios.	
Benelux-NRW economic value creation implied	●	■■
4- Universal integral implementations	• Small to negligible likelihood of Benelux-NRW LTD(s) being able to obtain a position in a Hyperloop supply chain for 'full' implementations dominated by technology developers and implementing companies originating from larger markets within and outside the EU; • Limited likelihood of cluster development for 'original' LTD(s), best opportunities for existing Benelux-NRW manufacturing leaders to include Hyperloop component(s) in their portfolios.	• Gains from connectivity improvements of introduction of full Hyperloop on specific niche corridor(s).
Benelux-NRW economic value creation implied	●●	■■■

Source: Consultant

5.5 Closing observations

The following table highlights a short-form version of the perspectives described above.

Table 11: Approaches, scenarios and outcomes (summary of strategic perspectives)

Which approach for Benelux-NRW to take?	*Which sufficiently plausible scenarios may occur?*	*What level of inputs is associated with each approach?*	*What are likely cluster realization and connectivity outcomes for each approach, under different scenarios?*	
		Level of Benelux-NRW (funded) inputs implied	Benelux-NRW economic value creation implied	
			Cluster realization outcomes	Connectivity outcomes
Drive for universal 'full' Hyperloop implement-tation		◆◆◆◆◆◆		
	1- No progress scenario		●	-
	2- Niche partial implementations		●●	■■
	3- Niche integral implementations		●●●	■■■
	4- Universal integral implementations		●●●●●●	■■■
Facilitate gradual develop-ment, choose specialization		◆◆◆◆		
	1- No progress scenario		●	-
	2- Niche partial implementations		●●●	■
	3- Niche integral implementations		●●	■■
	4- Universal integral implementations		●●●●	■■■
Let the market direct and decide		◆◆		
	1- No progress scenario		-	-
	2- Niche partial implementations		●●	■
	3- Niche integral implementations		●	■■
	4- Universal integral implementations		●●	■■■

Source: Consultant

This overview guides and informs considerations by Benelux-NRW policymakers with concern to the approach taken, the likely outcomes associated with each approach and the variability of outcomes depending on which plausible scenario of Hyperloop plays out in the medium- to long-term future.

Preferred approach depends on public sector investor risk profile(s)

In general terms, the level of risk tolerance of Benelux-NRW policymaking will be most decisive in assessing the attractiveness of (probability-weighted) long-term outcomes versus the level of short-term and thereafter sustained policy effort and public resources associated with each of the three highlighted approaches.

The three approaches presented in the table above can be differentiated according to their public investment risk profile accordingly: analogous to consumer investment profiling, they can be characterized as ranging from high-risk-high-return (drive for universal 'full' Hyperloop implementation) to low-risk-low-return (let the market direct and decide) approaches.

Limitations and observations to keep in mind going forweard

There are several limitations to this overview and this framework of strategic perspectives generally:

- No probabilities have been discussed or assigned for each scenario. Instead this study introduced each scenario as sufficiently plausible to be considered for its purpose (to assess the robustness of choices and the expected resulting balance of inputs and outcomes when faced with multiple potential futures of Hyperloop development).
- Whereas the relative significance of inputs and outcomes has been indicated, these have not been quantified. This means a concrete 'return on investment' or economic rate of return analysis is not included. Instead the analysis offers a process framework for discussion and decision-making, and a blueprint for potential quantitative analysis in the course of that process.

Nevertheless, the following overall observations which arise from these perspectives as well as from the various parts of this study merit close consideration:

- In general:
  - Progress is unlikely to be achieved unless Hyperloop is demonstrated to work at scale and in a functioning passenger transport system;
  - Regional-level (Benelux-NRW and/or EU) public sector funding and cooperation is essential to enable harmonization and coordinated roll-out of Hyperloop corridors and networks if the technology is to achieve eventually the status of a 'regular' transport modality;
  - In particular replacement of air traffic seems to have substantial potential depending on competitiveness of aviation as a transport mode going forward;
  - The dominant driver of long-term economic growth is technology innovation. Any national or regional economy which succeeds to move the technological 'frontier' by piecing together a TRL9 successful Hyperloop system (or some of its key components) will capture, at least for some time, considerable economic benefits related to Hyperloop manufacturing and related spillovers.
- With specific relevance for Benelux-NRW:
  - No substantial economic value from Hyperloop-related technology innovation, supply chain formation and first-mover implementations will be captured by Benelux-NRW economies unless (some of) the first implementation activity takes place within Benelux-NRW borders. This will require a concert effort to enable integration into existing planning, permitting and funding mechanisms, infrastructures, zonings and other constraints.
  - Based on existing travel patterns and origin-destination data, two cross-border travel corridors have been assessed especially to be of potential value from a passenger transport point of view: (i) Amsterdam-Rotterdam-Antwerp-Brussels, and (ii) Maastricht-Aachen-Liège. These corridors may also serve as the 'guiding frameworks' for situating initial short (2-5 km) proof-of-concept system(s) which could thereafter be extended through the corridor.

- However, Hyperloop is expected to result in substantial changes to travel patterns and origin-destination data. One of the key conclusions is that it is essential to develop a multimodal analytical model that can assess the impact of fundamentally new modalities with high-speed and high-capacity as may be the case for Hyperloop.
- In addition successful early technology developers and manufacturers may be encouraged to establish and prosper within Benelux-NRW clusters, existing or newly established. The formation of such localized clusters can be encouraged and supported by governments, however more impact may be supporting technology developers in the optimization of their supply chains by aligning suppliers processes and willingness to invest with the needs of Hyperloop technology.
- In the mid- to long-term, it seems likely that technology OEMs from large markets would lead Hyperloop manufacturing clusters/supply chains, with the best position for Benelux-NRW economies to harbour production of several key components in the Hyperloop system due to experience, quality, strategic IP for those components and early-stage corporate networks continuing to prosper.

Annex 1: Data sources

To analyse the transport potential of Hyperloop connections in the Benelux for passengers and freight, a number of data sources were used. These are listed below.

Source	Description	Level of detail	Modalities	Remarks
Aeolus	Transport model for air traffic	Airport	Air	No access to the data
BasGoed	Origin-destination matrices, focused on the Netherlands	Multiple municipalities grouped	Road, rail, water, sea	Also assigns goods to a commodity type, and discerns between container and non-container transport
IntraPlan/LMS/NRM	Origin-destination matrices for passengers, focused on the Netherlands, used by ProRail	Multiple municipalities grouped	Road, rail, bus, air	Larger zones out of the Netherlands than inside of the Netherlands.
Vodafone data	Transport model based on GSM-data	Very high, up to road level	Road, rail, bus	Not maintained anymore
Airport data	Estimate of number of passengers by looking at number of flights	Airport	Air	Labour intensive to use, only results in an estimate

Annex 2: Stakeholders interviewed

The following stakeholders have been interviewed for this report, many of them more than once. Even though their inputs were crucial for the development of the findings, remarks and conclusions are the sole responsibility of the authors of this report.

Stakeholder
Innoenergy
Hyperloop Development Program
Hardt
Nevomo
Zeleros
Tata
Agoria
NS
Ministry of Transport of the State of North Rhine-Westphalia
Ministry for the Environment, Nature Conservation and Transport of the State of North Rhine-Westphalia
Ministry of Transport of the State of North Rhine-Westphalia
Ministry for the Environment, Nature Conservation and Transport of the State of North Rhine-Westphalia
RailCampus OWL
Flanders Make
Demcon
Denys
Ministère de l'Économie ofLuxembourg
Luxinnovation
Intis

Goudappel
Anna van Buerenplein 42
2595 DA Den Haag
The Netherlands
+31(0) 570 66 62 22

info@goudappel.nl
www.goudappel.nl

RebelGroup
Wijnhaven 23
3011 WH Rotterdam
The Netherlands
+31 10 275 59 95

info@rebelgroup.com
www.rebelgroup.com