Deliverable D 2.1
Observatory results

Project acronym:	HYPERNEX
Starting date:	01/12/2020
Duration (in months):	12
Call (part) identifier:	H2020-S2R-CFM/OC-IP/CCA-201X-0X
Grant agreement no:	101015145
Due date of deliverable:	Month 05
Actual submission date:	10-05-2021
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Dissemination level:	PU
Status:	Final

On May 10, 2021, this document is under review by the S2R committee. As soon as the final version is available, it will be updated.

Document history		
Revision	*Date*	*Description*
1	19/04/2021	First issue
2	27/04/2021	Revised version
3	08/05/2021	Approved for submission

Report contributors		
Name	Beneficiary Short Name	Details of contribution
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1. Executive Summary

The present document aims to formulate a complete observatory of the hyperloop system. Hyperloop is a mode of land transportation capable of high speed and driverless operations, in which a vehicle is guided through a low-pressure tube or system of tubes, for passengers and/or cargo. A new mode of intercity transport, designed to connect cities safely, efficiently, sustainably and autonomously, aiming to be safer, faster, economic, convenient and operating in all weather conditions. Challenges related to its deployment include, but are not limited to, the proposed maximum speed, environmental impacts, interoperability, operational readiness, capital costs, governance and the technical validation and industrialization of its system components.

The hyperloop system comprises of:

a) the vehicle, also called pod or capsule (structure, interiors and electric system);
b) the infrastructure (pressure maintenance systems, tube, interfaces (i.e. levitation, propulsion), stations, switches and airlocks, among others); and
c) the communication system (pods sensor data and commands and pods' location).

In regards to the stakeholders currently active in relation to the development of the hyperloop system in EU, the report identified 3 categories; research and public organizations, private companies and public and private initiatives. Existing hyperloop test facilities and their characteristics were recorded, along with, stakeholders researching hyperloop as a side-project. 84 documents were reviewed; half of which are scientific journals and the rest equally distributed between conference publications and reports. Europe contributes to hyperloop research with 40%, N. America with 25% and Asia 35%.

Following, two critical issues were examined: the legislation in place and the available funding opportunities for the development of the hyperloop. In regard to legislation, an important conclusion is that, on one hand, until the main hyperloop challenges are defined, it is difficult to establish a hyperloop focused legislation, on the other, it is of most importance to have a regulatory framework as soon as possible to grant that the hyperloop developments fit the required legislation in matter of safety and to obtain the maximum compatibility, interoperability and intermodality. Main aspects to be considered include safety and security; international travel, including issues such as border crossings and fees for infrastructure exploitation; operations legal framework; interoperability and standardization; and evaluation of conformity, including certification. Going to the funding issue, one of the main findings is that the hyperloop endeavour cannot be financed by one sole party, so a public-private partnership should be the main approach.

Coming to the hyperloop development and infrastructure, the first issue to be examined is the development of the stations. Based on information provided in the document they should be located at urban centres, integrated within an intermodal hub, simple, and enabling efficient passenger flow. To examine the potential of hyperloop in long distance development, this new transport mode is compared to aviation and high-speed rail. Hyperloop outperforms both modes when comfort and environmental friendliness are of paramount importance. When cost is taken into consideration, hyperloop is more cost effective for long distance routes.

In addition, hyperloop enables decarbonization as it is 100% electric with zero direct emissions and can be integrated in urban planning due to less needs for space and less noise impact. In terms of interregional travel, a specific case is included as an example, using the Silk Route, is proposed, considering a route spanning from 5,500 to 8,000 km.

Following the analysis, competitive factors in favour to the hyperloop are identified: significant reduction in end-to-end journey times relative to both air transport and maglev rail; very high operating frequencies; resilience, to weather conditions which may affect punctuality and cancellations; integration to high demand routes due to high costs entailed for the hyperloop infrastructure.

Finally, a gap analysis is conducted to identify research gaps, link them to research vision and propose research actions and directions towards reaching to successful implementation of the hyperloop system. The short- and long-term recommendations extracted from the gap analysis show that the next five years are critical to solve various technical issues to set the foundations for further creating a robust and sustainable design, whereas a long-term plan should focus on commercial tests to operationalize hyperloop.

2. Abbreviations and Acronyms

Abbreviation / Acronyms	Description
EMS	Electromagnetic Suspension
EDS	Electrodynamic Suspension
GJT	Generalised Journey Time
GSM-R	Global System for Mobile Communications-Railway
HSR	High-Speed Rail
HTS	High Temperature Superconductors
H-EMS	Hybrid Electromagnetic Suspension
LIM	Linear Induction Motor
LTE	Long Term Evolution
LSM	Linear Synchronous Motor
Maglev	Magnetic levitation
MIMO	Multiple-Input and Multiple-Output
PM	Permanent Magnets
SC	Superconducting Magnets
SRIA	Strategic Research and Innovation Agenda
SRLM	Switched Reluctance Linear Motor
TAM	Total Addressable Market
TUM	Technical University of Munich
UAE	United Arab Emirates
UHSR	Ultra-High-Speed Rail
WP	Work Package
WTP	Willingness-to-Pay

3. Background

The present document constitutes the Deliverable D2.1 “Observatory Results” in the framework of the tasks:

- T2.1. Identification of active actions and actors
- T2.2. Hyperloop concept and intermodal ground transport
- T2.3. Hyperloop and existing infrastructures
- T2.4. Hyperloop short term and long-term research vision

of WP2 “Observatory”.

It contributes to the rest of the technical WPs, namely WP3 “Technical definitions” and WP4 “Transferability and roadmap beyond HYPERNEX”.

4. Objective/Aim

The development of the hyperloop system represents one of the best examples of the way disruption transforms entire industries and sectors; decades after the last major change, it will be the fifth transport mode. Having in mind the goal set by the European Commission to use innovation as the main tool to keep the industrial and economic leadership in Europe, it is a fortunate event that the European talent is ahead in competition, hosting four out of the six most promising companies in the race to develop hyperloop. In order however to assess the current situation in terms of competing countries and industries, to identify strengths and weaknesses and to investigate what the next steps should be for European stakeholders, it is necessary to first create a complete observatory.

For this reason, the partners involved in the HYPERNEX project have identified as a main goal the joining of their expertise and capabilities and the creation of the so-called Hyperloop Toolbox. This will consist of a set of assets that match with the activities envisaged during the development of the project. Having said the above, the present document aims to report on all the activities undertaken throughout the course of WP2, which deals with the identification and description of the hyperloop ecosystem to achieve a minimum common understanding of hyperloop. More specifically, the goal of this WP is threefold:

1) To investigate involved parties and stakeholders in the sector of the hyperloop development considering the vehicles, infrastructure, energy supply and management, communications, maglev technology and more;
2) to identify and set a common understanding in regards to the hyperloop system having in mind issues such as intermodality, urban development, long distance development, integration in existing infrastructures, etc.; and finally
3) to investigate any other actions that may comprise competition against the development of the hyperloop system.

The specific objectives of the WP2 and hence of the present report are as follows:

- Identification and interaction with relevant initiatives and stakeholders in hyperloop development worldwide (including public, private and public/private initiatives), but focusing on the European territory.
- Identification of the market niche including the intermodal perspective, the integration of hyperloop within existing infrastructure, and
- Identification of its competitiveness factors and the outline of the hyperloop short- and long-term research vision as predicted and prioritized by all these initiatives.

5. The Hyperloop Ecosystem

5.1. Definition

The hyperloop, as agreed by all hyperloop companies, including the private hyperloop developers (Hardt, Hyperloop Transportation Technologies, Nevomo, Swisspod, TransPod, Virgin Hyperloop and Zeleros Hyperloop) at the Shif2Rail Hyperloop promoters' meetings, is defined, as a mode of land transportation capable of high speed and driverless operations, in which a vehicle is guided through a low-pressure tube or system of tubes, for passengers and/or cargo (Shift2Rail, 2020). It is a new mode of intercity transport, designed to connect cities safely, efficiently, sustainably and autonomously, in a fixed guideway tube-based infrastructure. The hyperloop is an ultra-high-speed mode of passenger and freight transport, with speeds up to 1,200 km per hour, which aims to become the fifth mode. It may also be described as a pod -and magnetic levitation- based mode of transport in a low-pressure-sealed tube or system of tubes that operates in a low-pressure environment to reduce drag, and increase efficiency to drastically reduce travel times (NETT Council, 2021). The hyperloop should be safer, faster, economic, convenient, it should operate in all weather conditions, be sustainably self-powered, resistant to earthquakes and not be disruptive to the existing infrastructure of the other modes along its guideway (SpaceX & Tesla, 2013). The system consists of sealed and partially evacuated tubes, connecting mobility hubs in large metropolitan areas, and pressurized vehicles (i.e., the pods), which can move at very high speeds, thanks to the contactless levitation and propulsion system it uses, as well as to the low aerodynamic drag (TUM Hyperloop, 2021). The hyperloop integrates technologies from multiple industries and its safe integration into the current transport system is depended on the adaptation of the existing standards and certification processes (NETT Council, 2020).

In Europe, the hyperloop has the potential to provide a sustainable solution to the growing demand for high-speed travel and to alleviate the rising challenges in transport, however there are still certain challenges to overcome. These may include, but are not limited to: the proposed maximum speed, environmental impacts, interoperability, operational readiness, capital costs, governance and the technical design of its system components (AECOM, 2020). Planning for implementation, considering standardization, legislation, policies and certifications, should already start in the early phases of the hyperloop development in order to create maximum benefit for future passengers and European citizens in general (Delft Hyperloop, 2019a).

5.2. Description of the hyperloop system

The hyperloop system operates in a low-pressure enclosed tube environment, allowing faster speeds for the elevated vehicle, usually called pod or capsule. A fusion of advanced technologies used on High-Speed Railway (HSR), aviation, aerospace and magnetic levitation applications is required for the successful implementation of the hyperloop.

A comprehensive overview of the hyperloop system is provided by focusing on the components of the system. These are:

- The vehicle (also called pod or capsule), which includes an aerodynamic fuselage (similar to the construction of a commercial aircraft), the interior and the electric subsystem.
- The infrastructure, which is composed by the tube, the sub-structure and the stations. The tube encloses and maintains the low-pressure environment ensuring minimum air leakage, its supporting structure -the pylons- and the guideway that could be on an elevated, on-ground and/or underground configuration. The infrastructure also contains the pressure maintenance system with each power substations, which provides a considerable reduction of air drag, allowing for a smooth travel of the pod with speeds up to 1,200 km/h. Infrastructure requirements are dependent on the type of levitation and propulsion system, both considered as the hyperloop interfaces, since they concern interactions between the pod and the track.
- The Communication system which creates an autonomous environment, exchanges data and coordinates operations, ensuring safety and comfort.
- Currently, the development of the hyperloop components is in different stages. Viable solutions to the core technologies have been revealed, however; testing infrastructures, standardisation and technology readiness assessment are important topics yet to be examined.

5.3. Pod

5.3.1. Structure

The pod structure is related to the fuselage, it is the main structural frame of the system and it is considered as equivalent to an aircraft airframe. Its design combines aerodynamics, material's technology and manufacturing methods with a focus on performance, as well as reliability and cost. It shall be designed as light as possible to accommodate external low-pressure conditions, design speed and will include on-board systems and interior furnishings, maximizing passenger safety, travel experience and comfort, inside a tube-based environment. The hyperloop pod is effectively a pressure vessel (with similar characteristics to the fuselage of aircraft), to withstand pressure differences and most importantly, to transport people and cargo.

For the conceptual design of a hyperloop pod, design guidelines for aircraft can be used. A cylindrical shape for the pod, in order to distribute efficiently the forces of the pressure difference, can be considered (Delft Hyperloop, 2019a). The pod design affects significantly the design of the tube infrastructure, depending on the loading pad configuration and the formation of distributed or concentrated loads (Santangelo, 2018). Lightweight materials such as aluminum alloys or composites with carbon fibers are viable options for the construction of the frame. In order to reduce design and manufacturing risk substantially, the pod structure could be decoupled from the external aerodynamic shell, creating a pod structure with two separate components: the structural-ladder frame and the aerodynamic shell. The aerodynamic shell is usually made from carbon fiber composites and covers all components of the pod to reduce the aerodynamic drag, as much as possible, at low-pressure environment (MIT Hyperloop Team, 2017).

5.3.2. Interior

Passenger safety and comfort inside a pod is based on a combination of best practices from rail and aviation transport, containing certified components of mature technologies. A human-centric interior design with augmented reality windows, lighting, colors, texture and control of sound levels will provide comfort, journey information (e.g., time to destination, exact location, speed, time, even simulations/videos of the external environment outside of the tube) and entertainment to the passengers. Interior furnishings and different evacuation options for emergency cases within the pod will be considered to maximize passenger safety and travel experience. Moreover, pod interiors will be designed to include first aid kits, automated external defibrillator (AED) machines and an emergency response call/communication system. Currently, conceptual designs of well-supported seats with seatbelts to protect passengers from rapid acceleration and deceleration have already been demonstrated, however testing seat design and safety considerations for passengers at high operating speeds is still required to establish the viability of such a concept. Passenger screening might be required and advice on how travel could affect pre-existing medical conditions should be provided (AECOM, 2020). Examples of concepts for the hyperloop pod and its interior are shown in Figure 1.

Figure 1. A hyperloop vehicle and interiors designed by Zeleros (Domingo, 2021) **and a human-centric conceptual design of the interior for the Virgin Hyperloop One** (Hitti, 2018)

5.3.3. Electric system

The pod's electric system is responsible for accepting power from the primary power system, storing energy for emergency backup and transferring power to auxiliary systems, similarly to those of a commercial aircraft or rail vehicle. Heating, ventilation and air conditioning systems will maintain a comfortable environment for passengers and equipment. Regarding thermal management, a smart thermal management system has been proposed by Hyperloop TT (HyperloopTT, 2019), with the capability to remove heat from various components of the pod and transferring it to a heat storage module will be developed. A real-time sensing and control system (able to be embedded on pods and infrastructure), for structural dynamics and aerodynamic sensing, is also under development and will be extremely compact, using hybrid circuit design (Janzen, 2017).

Currently, power supply concepts, that are affected by the potential construction cost and propulsion system, can be divided into the following three categories (AECOM, 2020):

1. Axial compressor propulsion with on-board power supply
2. Vehicle-side linear motor propulsion with on-board power supply
3. Infrastructure-side linear motor propulsion connected to the electrical grid

However, the technology readiness assessment of each separate category can affect decision-making and planning of hyperloop development. More detailed, on-board rechargeable batteries may provide power supply to the pod's system and multiple options to achieve fast charging are under development, including but not limited to: charging during the alighting, boarding process, when the pods are stored at the depot or at the stations during night. The pod also can be separated from the main route to be charged, transferring the passengers to a new vehicle as well as, its batteries can be replaced at the station.

Each pod may supply its own power for levitation, acceleration and control, as well as other amenities. A system to receive and store the electricity generated by regenerative breaking, is a considerable option (U.S Department of Energy, 2021). Nevertheless, certain challenges on using battery systems can be identified. Several important considerations about batteries are: the thermal management system and their mass which, may increase the pod mass by up to 30-50%, (depending on the journey time and other technology choices) and may contribute to increase of the power requirements and/ or to speed reduction. The use of batteries indirectly increases the infrastructure cost, since heavier pods require more robust infrastructure with additional charging facilities at the stations. Additionally, due to the need of charging or replacing the batteries after each journey, such a system can delay the availability of the pods. However, advances in the battery technology related to mass reduction and faster charging intervals might solve the aforementioned issues (AECOM, 2020).

Apart from the use of batteries, according to a recent study (Lafoz et al., 2020), supercapacitors could be considered a quite appropriate solution in hyperloop power supply, due to the fact that their power/energy ratio is very similar to the level required, however currently, there are several restrictive parameters which prevent their adoption in high power applications, including but not limited to their low voltage isolation limits and inefficient energy capacity. Nevertheless, analyzing the power/energy ratio and cycling requirements, increasing voltage limitation and avoiding at the same time premature loss of capacity, as well as testing, are certain factors that can elucidate the potentials of a currently speculative technology in the hyperloop power supply.

The use of hydrogen fuel cells could play an important role in reducing even more the pod weight and provide a solution to cool down the system.

On the other hand, an infrastructure-side power system, connected to the electrical grid may demonstrate several advantages, including but not limited to: better efficiency, reduced energy consumption, potential cost savings on the construction of the tube, higher manufacturing tolerances of the guideway, centralized and synchronized control of propulsion decreasing the potential of collisions. However, high infrastructure cost, fault tolerance, acquisition of considerable land area to house electrical substations are certain limitations associated with the use of such a system (AECOM, 2020).

The power demands of a fully operating hyperloop can induce grid interface challenges, however with the use of innovative designs, integration of the existing grid systems, advanced utility planning and buffering strategies, as well as, technology options that could either isolate or mitigate the direct impacts on the grid, potential issues on the electrical grid may be eliminated (U.S Department of Energy, 2021).

5.4. Infrastructure

5.4.1. Pressure maintenance system

The pressure maintenance system is a key component in the hyperloop system, it is responsible for the initial evacuation of air (pump down) and the steady-state condition of maintaining the required low-pressure environment. Hyperloop systems may rely on different pressure levels, with some of them working at pressure levels similar to civil aviation and others working at pressure levels similar to space.

The pressure maintenance systems and electrical power substations are important and comprise critical parts for the hyperloop design integration. Both systems are expected to be constructed outside the tubes at an appropriate spacing distance which is defined by the tube design, material and construction process. Pressure maintenance stations are expected to be smaller, more numerous than the electric power substations and may be housed in a separate building or attached to the tube exterior (AECOM, 2020). As an example, Figure 2 shows different types of pressure maintenance systems that have been used in different tests to create low-pressure environments, with sets of pumps, single pump and containerized systems incorporating pumps and ancillary equipment (including electronics and cooling).

Figure 2. Tube and pressure maintenance system test (left side) at Universitat Politècnica de València, Spain (Hyperloop UPV, 2019)**. Vacuum pumps (middle) to be tested in Virgin Hyperloop One** (Virgin Hyperloop One, 2016b)**. A vacuum pump unit (right side) with a modular housing to be tested in HyperloopTT** (HyperloopTT, 2019)

Defining an optimum pressure level, is a trade-off analysis between power required to maintain pressure, the power to overcome aerodynamic drag, among other factors, and the infrastructure derived costs (Zeleros, 2021a). A combination of backing pumps, to produce a low-pressure environment, with root pumps, to bring the pressure to the required level and to maintain it, can be used to create the environment required to overcome the aerodynamic drag. The variance in leakage, power-consumption of the pumps and the frequency of the pods may affect the optimal operational pressure (Delft Hyperloop, 2019a).

The pump-down[1] operation is the first step to achieve an operational pressure on the travel tube. Once, that is done, a steady-state phase is on process to maintain the required conditions (Decker et al., 2017). Theoretically, there is no need for the pressure level system to run, if the tube is perfectly air tight. However, in practice, the tube is not absolutely air tight during the regular operations and the air is going to leak particularly during the loading of the pod into the tube. Therefore, a continuous operation of the pressure pumps to maintain the required pressure level in the tube should be assumed (Janić, 2020). Additionally, it is likely that the initial pump-down would be the most energy-consuming with a large impact on cost while currently, the number of times that such an event would occur, remains unknown. However, this operation could be scheduled i.e., overnight, reducing the cost and impact on the wider grid (AECOM, 2020).

The power requirements to depressurize the tube in a reasonable time and the steady-state requirements to maintain the low-pressure environment in the tube are depending on the tube (Chin et al., 2015), as well as on the tube materials (Zeleros, 2021a). Electrical power substations are likely to be similar to the current Maglev systems and will be installed to connect -in a controlled manner- multiple subsystems to the electrical grid. According to many design proposals, power could be delivered through renewable energy sources; however no details

1 **Pump-down time** – The time needed to pump from a given pressure to another given pressure (Charky, 2018)

have been provided and its feasibility has not yet been proven (AECOM, 2020). Moreover, a more in-depth analysis of the pressure pump energy defining the exact value of the tube pressure, extensive CFD research, the energy required to maintain the pressure level and a long test track should be foreseen to have a clear view of the aforementioned sub-systems integration on the hyperloop (Delft Hyperloop, 2019a).

5.4.2. Tube

The tube provides a low-pressure travel-guideway environment by, decreasing the aerodynamic drag, it protects the pod from all external conditions and it is configured as an elevated structure, ground or underground level, supported by pylons at an appropriate spacing distance. The tube needs to be grade-separated or barrier protected from other transport modes (MORPC, 2020). It shall be airtight to maintain the low-pressure environment, strong enough to prevent puncture and be designed according to the geometry of the pod and the aerodynamics behaviour. These parameters will also depend on the pressure level of operation of the system (Zeleros, 2021a). The appropriate tube material and diameter depends on (Delft Hyperloop, 2019a):

- **Cost:** the economic feasibility of the hyperloop depends highly on the tube cost. New technological developments on a large scale may lower cost and ease construction. Tube thickness is an important factor as well, which should be able to withstand vacuum buckling.
- **Span suitability:** a high stiffness material to minimize the occurring deflections and to be suitable for spans. Pillar spacing, in turn, is a compromise between the structural integrity of the tube and the social impact like segregation.
- **Thermal expansion:** thermal fluctuations can lead to variations of tube size due to its large construction. A classic engineering issue with multiple solutions to be explored which might be, but are not limited to, prestressing, section gaps and expansion joints.
- **Workability:** to reduce cost and construction time. It combines producibility, since tubes should be produced in a short time and transportability, an efficient transport to the construction site.
- **Air tightness:** to maintain the low-pressure environment inside the tube, preventing higher drag, energy consumption and pumping effort.

Concerning the tube infrastructure, concrete pylons are expected to support a dual tube system with a height depending on the configuration of the guideway (Figure 3). Three types of guideway infrastructures are under study: elevated, on ground and underground. However, the elevated guideway is expected to be the safer, since there is no need for crossing control systems at roadway intersections. Also, the land footprint is smaller for pylons compared to a railway track. Leveraging the surface on top of the tubes, solar panels may also be installed, contributing to local electric grid by increasing the amount of clean and renewable energy (Transpod, 2019a).

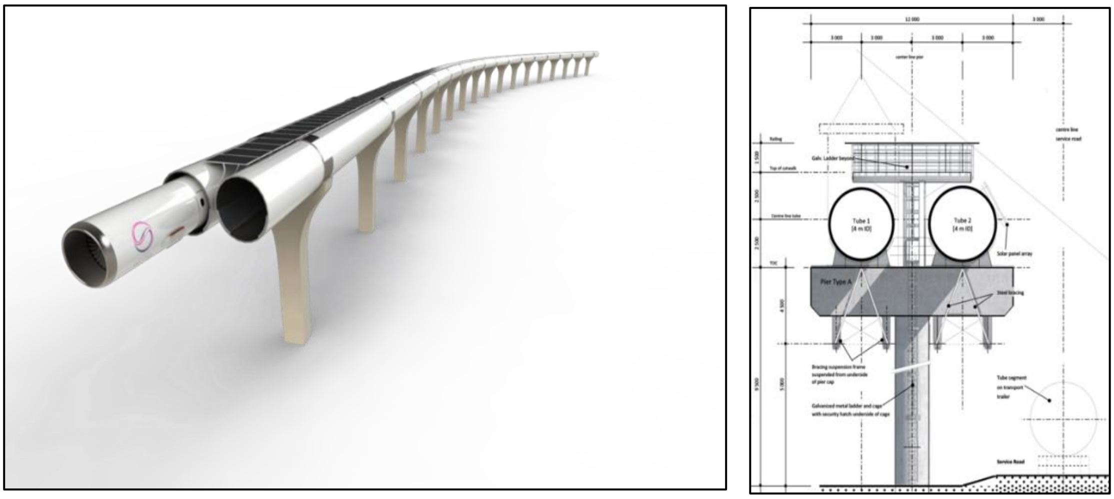


Figure 3: Conceptual design of the hyperloop tube infrastructure by Transpod (Transpod, 2019a)

Finally, the tube can be assimilated to the track in railway transport. Depending on the hyperloop system layout it may be necessary or not to change from one tube to another

The switches are track changing mechanisms, which allow the pods to pass from one track to another, realizing a point-to-point connection at a network of tubes, connecting various cities. They have to be energy efficient, with low maintenance and at the same time to be capable to allow the pods to change tracks without slowing down (Hardt Hyperloop, 2021). It has been reported that a promising aspect of hyperloop technology is that individual pods may never need to make intermediate stops, due to the fact that the small, frequent and autonomous pods allow for on-demand transport (AECOM, 2020). The capability of the pods to switch between tubes and to facilitate the change between the main and side routes (allowing the passengers to not stop at every station on route) will be enhanced by the development of switching technology (Chesterton & Davies, 2018). There is also a trade-off design consideration regarding the coupling between the design of switches and this of an optimal magnetic guidance and levitation system (TNO, 2017). Due to the fact that very little is known about their operation and feasibility, high-speed switching constitutes the most unique and complex elements of the hyperloop system. If the layout requires of switching, two primary scenarios have been envisioned by the developers. The first is envisaged to allow tubes to diverge towards different destinations. The second is to split the main tube in two, several kilometers from a terminal, providing additional capacity for the envisaged acceleration and deceleration stages and a larger number of portals- the entry or exit points from terminals (AECOM, 2020).

Regarding the testing infrastructure, a single tube with switches instead of a double tube can lower cost at approximately 20-30% (TNO, 2017). Moreover, the total cost for the hyperloop system is highly dependent on the number of switches necessary, since the cost for switches is higher than this for a normal track. Virgin Hyperloop (Virgin Hyperloop, 2021b) estimates that a switch will cost about 3 times as much as a normal track segment, but could potentially increase to as much as 6 times (TNO, 2017). On the other hand, Hardt (Hardt, 2021b) estimates that twice the cost of a normal track segment should be sufficient (TNO, 2017). Maintenance and monitoring of the high-speed switches are also required to ensure lateral guidance and safety, avoiding unexpected collisions (Delft Hyperloop, 2019a). Switching technology for hyperloop will be entirely novel and currently it is a fundamental factor on realizing a transport network with various routes and an efficient hyperloop operation; however, it is currently at very early stage, considered to be speculative, unproven and needs to be developed. Given the anticipated speeds the pods might reach, high-speed switches present a new, previously unimagined, challenge. Testing at full-scale, tube junctions with high-speed track switching will answer questions regarding the feasibility of developing a network of routes. Due to the complexity of the system and the tolerance of the mechanical systems, switching will occur at significantly lower speeds. Understanding the operation of switches, the possible failures and the risks involved in changing tube guideways at ultra-high speeds and the various operational complexities of the system, will enhance the development of such state-of-the-art technology (AECOM, 2020).

5.4.3. Interface - Levitation

Regarding the levitation subsystem, the first proposal suggested the use of air-bearings for levitation with a combination of a linear induction motor (SpaceX & Tesla, 2013). These systems require though high maintenance, tight integration between the track and the pod, on-board power. They increase significantly the pod weight with the use of fans, motors and hover-pads (Delft Hyperloop, 2019a; MIT Hyperloop Team, 2017). Therefore, subsequent efforts focused on magnetic levitation (Maglev) that can be coupled with the electromagnetic propulsion system for higher efficiency (Decker et al., 2017). According to recent comparison studies in levitation (AECOM, 2020; Delft Hyperloop, 2019a; Noland, 2021), there are several proposed methods for handling pod levitation, however two of them are, currently, the most dominant and have the potential to be compatible with the high proposed speeds of the hyperloop: the Electromagnetic Suspension (EMS) and the Electrodynamic Suspension (EDS), called “active levitation” and “passive levitation”, respectively.

More detailed, the EMS technology is based on the attractive properties of the magnets and it uses pod-side electromagnets and ferromagnetic materials on the guideway, which are actively controlled through switching the electromagnets on at a high frequency control system. Since the suspension force is independent of the movement, landing wheels are not required, however, stability will be ensured using an active control system. In order to achieve an energy-saving strategy as well as reduce the amount of heat losses, a hybrid EMS is a solution that has recently been proposed using permanent magnets (Grebennikov et al., 2018). Whereas, the EDS technology is based on the electromagnetic induction, it uses pod-side permanent magnets or superconducting electromagnets and highly conductive guideway infrastructure that generate opposing magnetic fields through induction. These produce a stable levitation force that does not require active control as long as there is relative motion between the pod and the guideway. However, forward motion is required (“lift-off speed”) to suspend under low speeds and at standstill, which constitutes a major drawback (Noland, 2021). In EDS, the pod can be levitated about 10mm to 100mm, using Permanent Magnets (PM EDS) or Superconducting Magnets (SC EDS), while the EMS works with magnetic forces giving a lower levitation at about 10 mm to 20 mm above the guideway, using electromagnets (Santangelo, 2018). Both systems can ensure safety at high speeds, low pollution since they are electrically powered, low maintenance and high capacity to accommodate increasing traffic growth (AECOM, 2020). A simplified comparison of the levitation systems is shown

Figure 4.

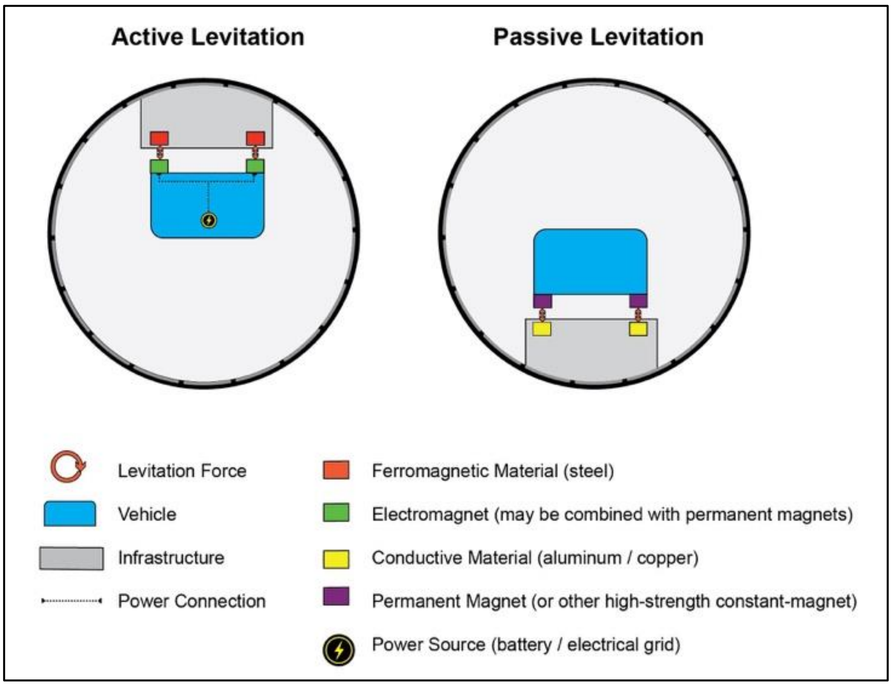


Figure 4. Simplified comparison of active and passive levitation systems (AECOM, 2020)

A technology that has been recently developed, using EDS and Neodymium-Iron-Boron magnets instead of superconducting magnets, is the Inductrack, which uses an array of permanent magnets (Halbach arrays) on the bottom of the pod, creating a magnetic repelling field when they pass over passive coils on the railway. Due to the high magnetic efficiency of Halbach arrays and the close-packed track circuits of this technology (Post & Ryutov, 2000), as well as, according to recent studies, comparing levitation systems (Delft Hyperloop, 2019a; Noland, 2021), leveraging the benefits of Inductrack, it could be considered a viable option for hyperloop, in terms of cost reduction and energy efficiency.

For the operational speeds of a hyperloop, feasibility of both technologies still needs to be proven. Additionally, constant power supply is required for both systems (AECOM, 2020). The EMS system depends on active control systems as well as the power supply on the electromagnets, and redundant systems should be installed to guarantee the levitation of the pod in case of a power outage. The potential of the track to be capable to charge on-board batteries to provide power for the levitation is under study, requiring though a constant monitoring to maintain the distance between the guideway and the pod, within a very small air gap. If an EMS system can reach the high operating speeds, there is a need of verification of the small air gap to be sufficient to prevent crash. The EMS system depends on active control systems and power supply on the electromagnets. Due to the relatively large air gap on EDS, track irregularities or other effects on the movement of the pod may have less restrictive requirements (Delft Hyperloop, 2019a). A summary of the pros and cons of the two systems can be found in Table 1 (Noland, 2021).

Table 1: Advantages and disadvantages of the main levitation systems for hyperloop.

Levitation System	Advantages	Disadvantages
Electro-Magnetic Suspension (EMS)	-Technically easy to levitate at standstill or at low speed -Simple guideway composed of ferromagnetic beams -Laminated track yields lift-to-drag ratio ³ 500 -Inherent guidance force from the salient magnetic circuit	-Inherently undamped & unstable operating principle -Requires precise monitoring to maintain levitation height -Electromagnets on board requires energizing power -Interference requires separate guidance-control for high speeds
Electro-Dynamic Suspension (EDS)	-Highest achieved levitation speed (i.e. 630 k/h) -No active control needed, i.e. inherently stable -No on-board energy is needed to sustain levitation -Large air gap, i.e. insensitive to track imperfections	-Pod needs low-speed auxiliary wheeled system (WRS) -Simple EDS generates a high drag energy consumption -Need magnetic shielding due to lack of magnetic circuit -Need a very sophisticated track to reduce magnetic drag

It can be concluded that, more research and development is required to increase the energy efficiency of both levitation systems in combination with the guideway configuration, ensuring its feasibility, as well as, to address issues of comfort and stability. Furthermore, a cost analysis comparison study is required to assess the feasibility of both systems, regarding infrastructure interface, as EDS system requires a conductive material and EMS requires an electrical steel rail.

5.4.4. Interface - Propulsion

The propulsion subsystem generates the motion of the pod creating propulsion, braking and in some cases levitation forces, and shall be capable to maintain its speed within the tube with high energy efficiency. Currently, the two main vehicle concepts in development use the linear motor as propulsion system, whether during the entire trip (i.e., Hardt, VHO, HTT, Nevomo), or only for the acceleration phase until reaching cruise speeds, using axial compressors for cruise (i.e., Zeleros, Transpod).

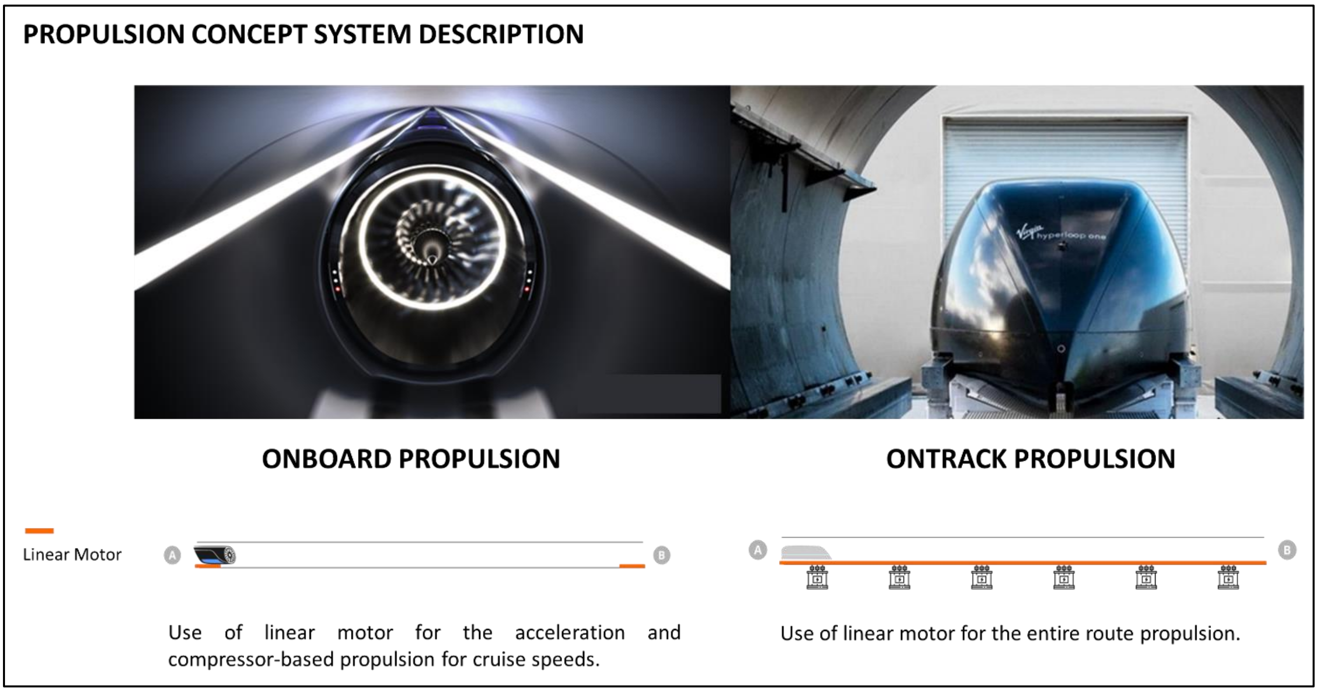


Figure 5: Two different concepts of propulsion. The linear motor is used only on the acceleration phase (left) or on the entire route (right).

Axial compressors compress air in front of the pod and generate thrust by forcing it out of the back at higher energy. For this technology that replicates the constructive concept of an electric aircraft, pros and cons can be found. The use of an axial compressor implies that the vehicle can effectively funnel part of the existing air inside the tube, therefore allowing the system to operate at aviation-level pressures. If the compressor is used as the single propulsion unit during most part of the trip (e.g., Zeleros' concept) it implies that the linear motor is removed from the track and consequently the associated cost of installation and maintenance of it. In summary, the pros linked to the use of axial compressor are related to the fact that removing the lineal motor cuts the cost of infrastructure significantly and also that operating at aviation-range pressure levels might incur in straight certification path for the vehicle as the legacy of safety regulation for mass passenger transport is much more developed than systems operating at space-range pressure levels. On the contrary, the use of this system incurs on limitations such as the added complexity of the system that must run by combining two propulsion systems and, also, that the cost of the vehicle increases significantly due to the fact that a compressor is added to it and also that in some configurations (e.g., Zeleros) the energy is supplied by onboard energy storage systems (e.g., batteries or hydrogen).

Regarding the linear motors, two systems are introduced, which produce a propulsion force electromagnetically and work in combination with levitation: The Linear Induction Motor (LIM) and the Linear Synchronous Motor (LSM). The LIM is a rotary motor consisting of a stator, which generates a varying magnetic field across an air gap and a rotor, which acts as a conductor on the induced electromotive force, creating eddy currents with its interaction with the magnetic field of the stator (Delft Hyperloop, 2019a). Therefore, a propulsion force is generated, however at high-speed operations (>>200 kph), the ability to transfer the high electrical power to the pod becomes impractical (Codot, 2004). Moreover, LIM is not compatible with EDS levitation and requires non-contact charging of the batteries during the journey (Delft Hyperloop, 2019a). Nevertheless, one key aspect of LIM is reliability (in a high-vehicle-density operation of a transportation system), which is based on existing conventional-rail technologies and has been well established (Codot, 2004).

In the Linear Synchronous Motor (LSM), the mechanical motion synchronizes with the magnetic field and the propulsive force is produced by the interaction of two magnetic fields. The LSM system consists of a number of permanent magnets on the pod and coils on the guideway, creating a traveling magnetic field (Thornton et al., 1993). Specifically, a stator that is located beneath the guideway produces a magnetic field along the guideway and an excitation system located onboard of the pod stimulates the levitation electromagnet to produce an excitation magnetic field (Santangelo, 2018). There are certain disadvantages regarding LSM: complexity and higher cost than Linear Induction Motor (LIM), interchangeability issues depending on system capacity and operational modes, the instability inherent to the magnetic system, and the fact that it requires pod location data to ensure operationality, are some indicative examples. Despite its disadvantages, the LSM is able to achieve higher pod speed and it may be a reasonable choice for an energy efficient hyperloop (Delft Hyperloop, 2019a). The LSM has been significantly evaluated at test tracks and is already in operation for the Transrapid maglev system (Cassat & Bourquin, 2011), however, the system's reliability should be evaluated by an extensive testing of the technology, collecting data of previous applications and lifetime testing data from the designed track (Codot, 2004). Linear switched reluctance linear motor is also under development due its low cost construction, capability of producing high propulsion force without using any PMs, more fault tolerance because of phase independence and high efficiency at high speeds (Seok Myeong et al., 2007).

Independently of the use of LSM or LIM, its use will increase substantially the cost of the infrastructure, as it has to be deployed all along the tube to produce the vehicle propulsion.

5.4.5. Airlocks

The airlocks are devices equipped with gate valves and aid to allow for loading and unloading of hyperloop pods inside the evacuated tube, without re-pressurizing the whole tube, facilitating at the same time the transition from atmospheric pressure to low pressure, and vice versa. Since the proposed pod frequency is high, an arrangement of multiple parallel operating airlocks is necessary to increase speed and efficiency of boarding-disembarking (TNO, 2017). The airlock design is constrained to various factors, such as the merging of boarding gates into the same hyperloop tube, as well as the requirement for a sufficient space to handle the volume of passengers, ensuring a safe and secure environment. Although such a technology is under study and development, airlocks will likely be based on existing vacuum technologies, lowering the technological risks involved in the development (AECOM, 2020). The following schematic illustrates a 3km test track with two tubes, enabling testing of the high or low speed switching and the performance of airlocks (Figure 6).

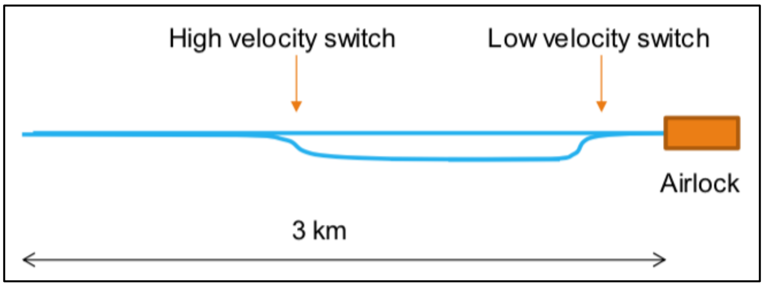


Figure 6. Schematic layout of a 3km long test track (TNO, 2017)

Although multiple options and innovative ideas have been developed so far, currently, airlock development can be divided into two main concepts/categories that constitute the most promising solutions, the pros and cons of them regarding the operation time, safety and structures, are demonstrated on the following table (Table 2).

Table 2. Pros and cons of the two main airlock concepts (Delft Hyperloop, 2019b)**.**

	Airlock chamber	Bridge doors
Advantages	Pod freedom at station. Fast (dis)embarking of passengers. Concept used often.	No large airlock mechanism. Minimal station space needed. Redundant design.
Disadvantages	Large mechanisms/doors. More station space needed. Wait time in airlock.	Extra (dis)embarking time. No pod freedom at platform. Low perceived safety.

The first concept accounts for an airlock chamber, in which a pressure variation is expected depending on the direction of the pod. This will include both expected cases, from atmospheric pressure to low-pressure-tube environment and reversely, with depressurization to occur once the pod is sealed. The second concept is related to bridge doors at the platform that will lock onto the pod doors allowing for the pod to be exposed only to low-pressure environment and connect the pod to the station atmosphere. In terms of safety criteria, operation time and minimum area is required for (dis)embarking, thus the first option is the most viable (Delft Hyperloop, 2019b).

The airlocks are among the most critical components of the hyperloop network, however commercially viable airlocks are still untested components. Addressing certain aspects such as: maintaining and monitoring a constant low-pressure over long tube segments and eliminating pressure failures at the airlocks, comparing the cost of various airlocks on emergency exits and boarding gates, as well as creating an effective and reliable communication system for a delicate management of the movement and monitoring of the system, will impact significantly the airlock development and its successful implementation into the hyperloop system (AECOM, 2020).

5.1. Communication system

A robust, scalable, secure and reliable communication system enables stable and autonomous guidance of the pod in the entire tube, ensuring safety and comfort. Pods should communicate with an external computing unit that processes data and actuates the pods. Two types of communication are required:

- The communication of the pods sensor data and commands to and from a centralized data processor.
- The communication related to the information about the pods location between the pod and the tube.

In addition, it is under discussion if a third level of communication will be necessary: the communication from pod to pod.

Challenges related to the pod communication with the outside world and the collection of data still exist and need to be addressed to provide reliable and high-speed connection between the pods and the infrastructure. According to recent studies (Delft Hyperloop, 2019a; Hyperloop Connected, 2020; Tavsanoglu et al., 2021), certain challenges need to be addressed, including, but not limited to the following:

- The tube, may prevent the use of wireless communication. In metal low-pressure tubes, losses are expected due to the permittivity and conductivity of the walls. The maintenance of the communication system is more difficult in low-pressure environment.
- The working frequency bandwidth. The hyperloop communication system will not be the only user of the LTE (Long Term Evolution-Railway) bandwidth. Coverage without interference is a significant topic, since other communication services will use different frequencies and a common network on multiple countries is questionable.
- The handovers, which are an integral part of the mobile communication system and due to the high speeds of the pod, constant connection to the infrastructure is challenging.
- The doppler effect, an increase in speed, leads to an increase of the shifted frequency which can lead to loss or misinterpretation of the data signal.
- The delay spread[2] is expected to be variable, due to the steel and carbon fibre structures and the reflections in elements like intermediate doors, track, antennas and any discontinuity of the surface of the tube.
- The penetration losses are expected to be high, due to the materials used for the tube and pod, steel and carbon fibre composites, respectively. Due to the penetration, losses are expected to be

2 ***Delay spread*** is a measure of the multipath profile of a mobile communications channel. It is generally defined as the difference between the time of arrival of the earliest component (e.g., the line-of-sight wave if there exists) and the time of arrival of the latest multipath component. Delay spread is a random variable, and the standard deviation is a common metric to measure it. This measure is widely known as the root-mean-square *delay spread* σ_τ (Grami, 2016).

in the range of 40-60 dB, the pod must be equipped with external antennas and repeats to provide coverage inside. However, appropriate design, access and emergency doors and other connections of the tube are expected to reduce the penetration loses.

- The MIMO (Multiple-Input and Multiple-Output) capabilities in tunnel environments are very limited, due to the propagation characteristics of the channel, the difficulty of positioning the antennas with the optimal separation and orientation and the different propagation channels are highly correlated.
- Cybersecurity, a growing concern of many infrastructure systems. The communication system and their protocols could be compromised by external or internal unauthorized access (e.g. cyber-terrorism) (AECOM, 2020). Cybersecurity is a very important concern for hyperloop development, since terrorist attacks can have severe consequences (Gkoumas & Christou, 2020a), while surveillance on very long distances could be very challenging.

Optical fibre communication is a technology with a great potential to solve the aforementioned challenges and wireless communication between antennas with radio waves is considered an effective option for wireless data transport (Delft Hyperloop, 2019a). Currently, the GSM-R (Global System for Mobile Communications-Railway) is the primary communication system for most of HSRs. Due to certain limitations of the GSM-R and the rapid growth of railway services, LTE-R shall be considered as the next generation communication system, providing capabilities for data transmission and passengers services such as Internet access and high-quality voice or mobile video broadcasting (Ai, 2014). Improving the current technologies and creating new communication protocols, such as the 5G, may lead to important advancements in the communication performance of the Hyperloop. A communication system capable to operate with high capacity and quality of service may be feasible, by optimizing the communication design using recent technological advances, such as Wi-Fi 6 and 5G New Radio, as well as, creating a communication test environment that allows for emulating the operation of communication systems at mobile speeds of up to 1,200 km/h (Tavsanoglu et al., 2021).

6. Stakeholders and Actions

This section identifies different stakeholder categories that are engaged in activities related to the hyperloop system in EU. These EU stakeholders refer to organizations that their main goal and/or objective is the development of the hyperloop system. To capture different aspects related to the hyperloop system and its components, the considered stakeholder categories are:

- Research and public organizations
- Private companies
- Public and private initiatives

Additionally, to gain a global perspective on hyperloop system, the fourth subsection records existing hyperloop test facilities and their characteristics, and the fifth subsection records those stakeholders that have researched hyperloop as a side-project rather than being their primary research field. These stakeholders may research or/and work on innovative concepts for guided transport modes including railway, vacuumed tube infrastructure and transport, and other ground transport modes. The data collection considers several hyperloop components as these identified in section 5, including the pod and the infrastructure. This information is synthesized with findings about hyperloop stakeholders at global level and publications on hyperloop to allow the identification of a ground transport community and its interactions.

6.1. Research and public organizations

ADIF:
Adif (Administrator of Railway Infrastructures) is the national Infrastructure Manager in Spain, which manages and maintains the Spanish railway Network, a state-owned public company that answers to the Ministerio de de Transportes, Movilidad y Agenda Urbana. This network has a part that belongs to the Trans-European Core Network Corridors with more than 6,300 km. It manages the second largest high-speed rail network in the world (Adif, 2021). Adif started its involvement in hyperloop when it signed an agreement in 2018 with the American company Virgin Hyperloop One to establish an R&D center in the south of Spain (Adif, 2018). The project was halted, but the company has followed the hyperloop activities held at the Railway Innovation Hub in Málaga, where Zeleros created a hyperloop working group (Railway Innovation Hub, 2019b).

CEDEX:
Founded in 1957, the Centro de Estudios y Experimentación de Obras Publicas (Center for Studies and Experimentation of Public Works) is a cutting-edge autonomous body applied to civil engineering, building and the environment (CEDEX, 2021)and it is dependent on the Spanish Ministry of Transport, Mobility and Urban Agenda (MITMA), which has included hyperloop as a priority in its Innovation Plan since 2017 (MITMA, 2017). The organisation is composed by different laboratories such as the Center for Transport Studies and the Railway Interoperability Laboratory (RIL/LIF), the world's first accredited to test components and lines equipped with ERTMS (European Rail Traffic Management System) to work in this railway signalling system unified by the European Union (CEDEX, 2000). CEDEX has published its plans to create a

hyperloop laboratory in 2021 including a tube test-track for high-speed testing (PTFE, 2020) and has actively participated in hyperloop standardisation. Jorge Iglesias, one of its representatives, holds the Chairmanship of the mirror committee of the CEN/CLC JTC20 in Spain.

CIEMAT:

Founded in 1951, the CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas) is a public research body assigned to the Spanish Ministry of Science and Innovation under the General Secretariat for Research, focusing on energy and environment and the technologies related to them. Its team of 1,328 people is structured around projects which form a bridge between R&D&I and social interest goals (CIEMAT, 2021). The organisation's department for Electric Drives has cooperated since 2018 with the company Zeleros to develop a Switched Reluctance Linear motor for initial acceleration. This particular solution was preferred over permanent magnet machines such as Linear Synchronous motors or Linear Induction motors due to its robustness, simplicity and reduced cost (CIEMAT, 2020a). In 2020 the organization signed an agreement with Zeleros to further develop hyperloop related technologies such as linear drives (including superconducting machines) for highspeed transport (CIEMAT, 2020b) and several papers have been published about it (Lafoz et al., 2020; Lafoz & et. al, 2020)

Delft University of Technology

Inspired by Elon Musk's visionary idea and challenge, 36 students from the Delft University of Technology joined forces and founded Delft Hyperloop (DelftHyperloop, 2021). The team set out to design and build one of the first Hyperloop pods ever, with which they competed in the 1st SpaceX Hyperloop Competition. The pod features a unique design and levitation mechanism, enabling efficient and smooth travel. During the competition in California in January 2017, the pod was scored on speed, safety, efficiency, and scalability of the design. Out of 2,000 competing teams, Delft Hyperloop has won the overall first prize. In the summer of 2018, Delft Hyperloop compete with a new criterion compared to their predecessors: top speed. Delft Hyperloop managed to finish in second place, due to an overheating of the temperature sensor on the motor controller, the pod came to a standstill after reaching a speed of 142 km/h.

DLR - Next Generation Train (NGT)

The DLR researches a new train concept consisting of three types of trains. The NGT HST (Siefkes, 2021a), a high-speed train for the long distances, the NGT LINK (Siefkes, 2021c), InterCity train, and NGT CARGO (Siefkes, 2021b),which will be integrated in the operating concept. The main goals of the NGT project are shorter travel times and reductions in energy consumption, noise emissions, and wear, while increasing passenger safety and comfort and reducing life cycle costs. To achieve these goals, an operational concept of high-speed trains was developed: the 400 km/h passenger train NGT HST, using the main high-speed lines, and the 230 km/h intercity train NGT LINK, to feed passengers from the surroundings to the NGT HST. Complementary to NGT, a freight train (NGT CARGO) with accompanying logistics concept is currently being developed and integrated into the operating concept of the passenger trains.

EPFL Hyperloop

EPFLoop (EPFLoop, 2019), a team of motivated and extremely passionate students from EPFL, Switzerland participating in the 2019 HyperLoop Pod Competition held by SpaceX. Their work focusses on the design, tuning and optimization of the dynamic parameters of a set of custom suspensions capable of smoothing the inhomogeneities of the SpaceX tube track allowing only a max deflection of 5 millimetres at 400 km/h. Numerical analyses with finite elements for the viscous dampening in the suspension and the final vibration profile have been first realised in Comsol software and then verified with laboratory experiments on the shaking table.

ETH Zürich - Institute for Transport Planning and Systems

The project "Automation between Substation and Rail: Estimation of Existing Energy Saving Potential" aims to automate gradually the Swiss railway network. Based on literature, automation does not only promise to allow a more precise operation, but also opens possibilities to reduce the energy demand. Simultaneously, the aim of a more environmentally friendly and sustainable mobility is well served. Thus, there are different reasons to investigate the energy saving potential linked to the automation of railways. Towards this objective, an evaluation of real-world data from operations is performed on a larger scale (ETHZurich, n.d.).

- Energy data collected at the vehicles, containing information on power, position, and speed second by second
- Data from the management system, allowing e.g., to draw conclusions on signals influencing the train run (i.e., yellow or red-light aspect)
- Weather data allowing to estimate influences of the environment, e.g., wind and temperature.

Students from the ETH Zurich participate in the Swissloop Team (Swissloop, 2021). The Swissloop Team consists of twenty-five motivated students from various Swiss universities with backgrounds in mechanical and electrical engineering, industrial design, business, law and communication. They are supported by a network of alumni, advisors and partners in the industry and they actively participate in the SpaceX competition. Swissloop and the EuroTube Foundation (EuroTube, 2021) work on a large variety of research topics in the field of hyperloop and related areas including, cooling systems, safety systems, structural mechanics, fluid dynamics, power electronics, communication and control systems, mechatronic and performance research and use/feasibility case studies.

EuroTUBE

The Euro Tube Foundation (EuroTube, 2021) is a non-profit research organisation and incubator for sustainable vacuum transport technologies. The mission of the Euro Tube Foundation is to provide neutral research and technology testing grounds at central locations in Europe. At its Swiss base in Collombey-Muraz, the Euro Tube Foundation develops the necessary infrastructure technologies to facilitate its first, 3 km-long test track that is designed to the needs of university research groups, the growing industrial and start-up ecosystem for vacuum transport.

HFT Stuttgart

The Business Psychology program of the Stuttgart University of Applied Sciences in close cooperation with Hardt Hyperloop, a start-up from the Netherlands, studied the acceptance of potential users regarding Hyperloop for the first time. They conducted a representative study between 8th-25th July 2020; 387 participants from the Netherlands reported their willingness to use hyperloop. With this study important insights into the acceptance of hyperloop among the population are gained (Planing, 2020).

HYPED

HYPED (Hyped, 2021) is a team of students at the University of Edinburgh dedicated to the development of the hyperloop concept. They have received awards from SpaceX, Virgin Hyperloop One and the Institution of Civil Engineers.

Hyperloop UPV – Universitat Politècnica de València (Polytechnical University of Valencia)

Hyperloop UPV (formerly known as Hyperloop Makers UPV) is a team of students at the Polytechnical University of Valencia, Spain, participating in the SpaceX competition. Hyperloop UPV won the first Hyperloop Design Concept Award for the overall hyperloop system together with the Propulsion Subsystem Award in January 2016 (Rodriquez, 2016).

Hyperloop UPV has participated in all hyperloop competitions being in the global Top 10 and winning the Innovation award in last SpaceX Pod Competition in 2019 (HyperloopUPV, 2021a). The team has manufactured and tested three main hyperloop prototypes (Valentia, Turian, Atlantic) (HyperloopUPV, 2021b) and is hosting the European Hyperloop Week in Summer 2021 (Valenciaplaza, 2021).
In parallel, researchers and professors at the University have advanced in the research and definition of hyperloop commercial systems:

- ICITECH and the School of Civil Engineering have supported Hyperloop UPV in the construction of the first Spanish tube test track, a 12m tube laboratory that is used for vehicle testing creating large volume low-pressure environments (HyperloopUPV, 2017).
- DIIT Dept. of Transport Infrastructure and Engineering: has reportedly participated in Zeleros hyperloop feasibility studies for transport economics.
- CMT, a research and postgraduate educational centre fully involved in the R+D of Applied Thermo-Fluid Science, has supported Zeleros to validate its developments in aerodynamic electric propulsion systems.
- DISA: the Department of Systems Engineering and Automation has supported thesis from different researchers in the hybrid-electromagnetic suspension (H-EMS) levitation system of Zeleros hyperloop concept (Zeleros, 2021g).
- DIE: the Department of Electrical Engineering has supported the Hyperloop UPV team in the testing of complex power and motor drives for several hyperloop working prototypes.
- Val Space Consortium (VSC): has supported the Hyperloop UPV team in the testing of low-pressure hyperloop system.

ITE - Instituto Tecnológico de la Energía:

The Energy Technological Institute (ITE) is a Spanish non-profit association based in Valencia whose services, products and technological projects are addressed to national and international public bodies and companies in the power, electric, electronic and communications sectors (ITE, 2020). ITE has participated in several innovation projects in relation to battery storage systems for hyperloop vehicles together with Zeleros and other partners (GVA, 2018)(ITE, 2018).

ITENE:

ITENE is a Market-oriented research center specialized in Packaging, Transport and Logistics, offering business solutions to companies with a holistic vision in the mobility sector. ITENE has intervened in more than 488 projects within the European, national or regional scope in which it has collaborated with 83 scientific and technological agents (ITENE, 2021). ITENE has participated in the development of feasibility studies for Zeleros' hyperloop systems and its application to the freight and logistics sectors, as reported by Zeleros, under an H2020 Phase 1 Project (CORDIS, 2020).

IK4 Ikerlan - CEIT

IK4-IKERLAN is a not-for-profit Technological Research Centre located in the north of Spain, renowned for its capacity for innovation and comprehensive product development in smart mechatronic systems. The six areas in which it has a high level of specialisation: embedded systems, power electronics, micro technologies, energy, mechatronics and advanced manufacturing (Ikerlan, 2021). Zeleros has reportedly worked with the research centre (Zeleros, 2021f).

KTH Royal Institute of Technology

KTH Hyperloop (KTH, 2018) is a research team of students participating in the SpaceX competition. The goal is to develop the Hyperloop technology and know-how in Sweden. A model of a hyperloop pod is being developed to compete against other teams in the competition. The goal is to develop the Hyperloop Technology and the know-how in Sweden as well as competing in the upcoming SpaceX competition. The team aims to make a scaled prototype of around 2.5-3.0 meters long hyperloop pod with all the subsystems (i.e., braking, propulsion, levitation, electronics, magnetic, design and chassis). At the competition, the goal is to achieve the highest speed of all the competing team since the speed is the winning criterion - the record for 2019 was 467 km/hour.

Norwegian University of Science and Technology

Shift Hyperloop is an independent non-profit organization founded in Trondheim by students from the Norwegian University of Science and Technology. The team currently consists of about 50 members from various programs. Shift Hyperloop (Shift Hyperloop, 2021), works designing and building a hyperloop pod to be tested at SpaceX Hyperloop Pod Competition in California.

Renfe

Red Nacional de los Ferrocarriles Españoles (Renfe) is the Spanish national railway operator, a state-owned public organisation, providing passenger and freight service on infrastructure owned by the Administrador de Infraestructuras Ferroviarias (ADIF). Renfe is a leader in rail transport for passengers and goods and a point of reference in the mobility sector in Spain. The Renfe seal is a global point of reference for Alta Velocidad (high-speed rail), operating the second largest network of high-speed rail in the world after China, and exporting this knowledge abroad. Renfe became one of the first European public operators to support hyperloop, when in 2019 it included Zeleros in its start-up accelerator (Renfe, 2019). Since then, Renfe has supported the company in the route analyses and bringing all their experience in the operations of high-speed ground transport systems to hyperloop.

Strathloop

Strathloop is the University of Strathclyde's Hyperloop Pod Competition team, which is comprised of over 90 undergraduate and graduate students in various degree disciplines. The team focuses on revolutionize passenger and freight transport by prototyping a vactrain system: a supersonic railway which uses maglev technology in vacuum tubes. The team is divided in sub-teams, that work on: propulsion systems, levitation systems, chassis integration, power systems, suspension and stabilization, body and aerodynamics, braking systems, navigation and control systems, scalability and infrastructure (Strathloop, 2021).

Technical University of Munich - TUM Hyperloop

In 2015 a student initiative was founded at the Technical University of Munich (TUM) to develop and build prototypes for the SpaceX Hyperloop Pod Competitions. Over the last half decade, the team has won all editions of the event and gathered extensive experience in the field of ultra-high-speed ground transport. In 2019 the TUM, working closely together with the successful student initiative NEXT Prototypes, has launched the ambitious TUM Hyperloop program with the aim to design and build a full-scale ultra-high-speed ground transport system, based on the ideas of the Hyperloop concept. To fulfil its goals, the team works both on developing the necessary technology and its components as well as on investigating and optimizing the system, considering aspects such as safety and economic feasibility. A 24-meter-long demonstrator including a full-scale pod is currently in development and it is going to be built and put into operation in 2021 (TUM Hyperloop, 2021).

Tecnalia

Tecnalia is a leading Research and Technological Development Centre in Europe, whose mission is to transform technology into GDP to improve people's quality of life, by creating business opportunities for companies, being member of BRTA (Basque Research and Technology Alliance). Their main scopes of action are: digital transformation, advanced manufacturing, energy transition, sustainable mobility, health, and the urban ecosystem. Tecnalia has actively participated in the hyperloop working group at the Railway Innovation Hub (Railway Innovation Hub, 2019a) and is reportedly a partner from Zeleros in the hyperloop technology development (Zeleros, 2021f).

The International Maglev Board

The International Maglev Board (Maglev Board, 2021) a non-profit organization, made up of internationally known transport scientists, engineers, experts as well as members of citizens' movements. It is beholden to no corporate interests.

University of Applied Sciences Emden/Leer and Carl von Ossietzky University of Oldenburg HyperPodX (EU HyTeC)

The team is composed of students in Engineering Physics as well as Computer Science, Mechanical Engineering, Electrical Engineering and Economics. It started by participating in the SpaceX Hyperloop Pod Competitions as HyperPodX. The team renamed later to EU HyTeC. They focus on bringing different European hyperloop initiatives and partners together to create a research infrastructure at the existing large-scale Maglev test facility. Working with the Ministry for Science and Culture of Lower Saxony, the initiative EU HyTeC is focussing on refurbishing the 31.5 km MagLev Test facility in Lathen, Germany, to become the largest-scale European Hyperloop Test Facility (HyperPodX, 2021).

UPM:
The Technical University of Madrid is a public university, located in Madrid, Spain. Different departments from the University including fields such as mechanical engineering, railway aerospace, telecommunications, among others, have been involved in hyperloop research (Tavsanoglu et al., 2021). UPM is the coordinator of the HYPERNEX project (UPM, 2020).

Valenciaport Foundation:
Fundación Valenciaport is an Applied Research, Innovation & Training centre providing services to the port and logistics cluster. This initiative of the Port Authority of Valencia has enjoyed the collaboration of notable businesses, universities and institutions from the port community. Since its establishment, it has developed projects in more than 60 countries, primarily Mediterranean nations, as well as from the rest of Europe, Asia and Latin America. The organization has cooperated with Zeleros to develop hyperloop-based solutions for freight transportation decarbonisation (Valenciaport, 2019).

6.2. Private companies

DGWHyperloop
DGWHyperloop is an Indian hyperloop company founded in 2015, as a subsidiary of Dinclix GroundWorks (DGW Hyperloop, 2020). In 2016, plans were unveiled to develop hyperloop in India, and in 2018 a feasibility study was conducted for the Delhi-Mumbai Hyperloop Corridor. The feasibility study resulted in the establishing of Hyperloop India, a side project of DGWHyperloop, dedicated solely to construction of the hyperloop corridor between Delhi and Mumbai (Hyperloop India, 2019).

Hardt
Hardt is a Dutch company developing hyperloop. Like many hyperloop companies, it was established as a result of transforming a university team, in this case TU Delft Hyperloop, which won the SpaceX Hyperloop Competition in 2017 (TUDelft, 2017). In December 2019, Hardt announced the building of Europe’s first hyperloop test facility in the province of Groningen in the Netherlands (Hardt, 2019a). In 2019, an international business consortium led by Dutch clean energy conglomerate Koolen Industries had made a multi-million-euro investment in Hardt (Hardt, 2019b). The European Hyperloop Center is expected to be completed by 2022. In December 2020, Hardt announced the Hyperloop Development Program, a public-private partnership between the Dutch Ministries of Economics and Climate and Infrastructure and Water Management, the Dutch Province of Groningen and a group of industry parties and research institutions (Hardt, 2021c; HDP, 2021). In 2021, as part of the Hyperloop Development Program, Hardt announced plans to construct a pilot cargo route between Rotterdam and

Amsterdam (Hardt, 2021a). The preconditions and effects of a hyperloop connection for cargo between important and volume-intensive hubs in the provinces of Noord and Zuid-Holland are researched by an extensive coalition of (inter) national companies, governments and network organizations.

Hyperloop Transportation Technologies
HyperloopTT is an American hyperloop company established in 2013. The company is operating worldwide, with their offices located in Los Angeles, Sao Paulo, Barcelona, Toulouse and Dubai (HyperloopTT, 2021a). In 2017, Hyperloop opened the European Hyperloop Research and Development Centre in Toulouse, where they run full-scale tests, optimize and integrate all technical components of the system (HyperloopTT, 2021b). In January 2017 HyperloopTT began a strategic partnership with two cities in United Arab Emirates (UAE) (Zawya, 2017), and in 2018 it was decided that HyperloopTT in collaboration with Aldar Properties will build a commercial hyperloop system in Abu Dhabi (HyperloppTT, 2021). In December 2020, HyperloopTT decided to start a partnership with Hitachi Rail (HyperloopTT, 2020), with plans to integrate the hyperloop system with Hitachi Rail's signalling technology ERTMS.

Nevomo
Nevomo (Nevomo, 2021) is a Polish company developing hyperloop, established in 2017 by a group of students from the Warsaw University of Technology that took part in the Hyperloop Pod Competition II organized by SpaceX. Nevomo proposes to introduce hyperloop in stages, which will allow to engage conventional railway companies and their assets in the transition:

- Magrail – a unique mix of magnetic levitation operating on existing railway tracks at a speed of 300 km/h – 550 km/h. Magrail is a hybrid solution, which allows for both magnetic vehicles and conventional trains to operate on the same lines.
- Hyperloop – bullet pods moving at speeds of up to 1,200 km/h in low-pressure environment. The subsystems tested in the Magrail phase will be used here.

In October 2019 Nevomo held a demonstration of a Magrail vehicle in Warsaw. The 48-meter track was in a 1:5 scale. The maximum speed during this test was about 50 km/h, acceleration 6 m/sec^2 and deceleration 15 m/sec^2. In June 2020 Nevomo started a cooperation with IDOM, a world-leading infrastructure company specializing in feasibility studies. Nevomo has previously collaborated with companies such as Microsoft, DB Schenker and LOT Polish Airlines. In 2020 the company successfully run mid-scale tests, and in 2021 it will work on a full-scale test track. The company focuses on magnetic rail technology and builds its core competencies mainly within power electronics and linear motors.

Swisspod Technologies
Swisspod Technologies (Swisspod, 2021) is a Switzerland-based transport company developing hyperloop, which was founded in 2019 by two participants of the SpaceX Hyperloop Competition (Swisspod, n.d.). In September 2020, Swisspod was in the top three start-ups contributing to environmental protection in the Greentech Festival (Swisspod, 2020). The company aims to focus mainly on the development of hyperloop pods.

TransPod
TransPod is a Canadian French company designing hyperloop that was established in 2015. In November 2016, TransPod raised a $15 million from an Italian high-tech holding group (Born Digital, 2016). TransPod operates worldwide and in 2019, TransPod announced the opening of a subsidiary TransPod France, in order to further expand their operations in France (Transpod, 2019b). Additionally, in 2019, plans were unveiled for TransPod to open a test facility and a test track in Droux, France. In August 2020, TransPod signed a Memorandum of Understanding (MoU) with the Government of Alberta in Canada (Transpod, 2020). The MoU and its objectives were named as Alberta TransPod, which includes an R&D phase, a test track construction and high-speed tests, and finally the construction of a full inter-city line between Edmonton and Calgary (due to start the construction process in 2025).

Zeleros
Zeleros founded in Valencia in 2016, by Hyperloop UPV team – a university project awarded at the SpaceX Hyperloop Design Weekend Competition in 2015 (Zeleros, 2021h). Zeleros is a deep-tech company that designs, develops, manufactures, and commercializes hyperloop vehicles. To deploy its vision, Zeleros collaborates with global first-class technologists, industrials, researchers, and innovators. In June 2019, Zeleros announced that they were partnering with Siemens, a rail global market leader (Zeleros, 2019). Zeleros technologies integrated in the vehicle reportedly reduce infrastructure costs radically and enable operation at safe pressure levels which make the system easier to maintain and certify (Zeleros, 2021a). In June 2020, Zeleros completed a financing round worth of 7 million EURO (Zeleros, 2020), with the capital from Altran (France), Grupo Red Eléctrica (Spain), Goldacre Ventures (UK), Road Ventures (Switzerland), Plug and Play (USA), and the Spanish Angels Capital and MBHA. In January 2021, Zeleros was selected as one of the 20 most sustainable and competitive industrial companies to drive the post-pandemic recovery strategy for the Valencia region (Zeleros, 2021c) and among the top European companies by EIT (EIT, 2019). Furthermore, in January 2021, Zeleros announced a partnership with CIEMAT (Centre for Energy, Environment and Technology), a research centre in Spain under the Ministry of Science and Innovation of Spain (Zeleros, 2021d) and with Airbus, in March 2021 (El Espanol, 2021). For the next three years, the company has designed a plan to demonstrate the feasibility of its unique concept by validating the pod's core subsystems in lab conditions, along with the construction and testing of a 1:3 scale vehicle in a 3 km test track and the design of the real-size system. The company has received public support from the European Innovation Council, the European Institute of Technology and Innovation (EIT) Climate-KIC, the Eureka Eurostars programme, from CDTI (Spanish Ministry of Science) and European FEDER funds from Generalitat Velnciana (IVF, AVI, IVACE) (Zeleros, 2021e).

A non-European hyperloop company that should be noted due top to its contribution to the hyperloop development is Virgin Hyperloop.

Virgin Hyperloop is an American transportation technology dedicated to developing the hyperloop system. It was established in 2014, making it one of the first companies of its kind on the market. In July 2016 Virgin Hyperloop opened Hyperloop One Metalworks, a hyperloop manufacturing plant in Nevada, which produces hyperloop components (Virgin Hyperloop One, 2016a). In July 2017, Virgin Hyperloop completed a full systems Hyperloop test in a vacuum environment, which took place at the company's test track DevLoop in the Nevada Desert (Virgin Hyperloop One, 2017a). In October 2017, the Virgin Group invested in Hyperloop One (the name of the company at that time) and the two begun a strategic partnership, with Hyperloop One becoming rebranding and becoming Virgin Hyperloop One (Virgin Hyperloop One, 2017b). In November 2020, Virgin Hyperloop conducted the first in the world passenger tests in a hyperloop pod in their vehicle XP-2, at their DevLoop test site in Las Vegas (Virgin Hyperloop One, 2020).

6.3. Public and private initiatives

European Hyperloop Week

The European Hyperloop Week is an international event that brings together the most competitive part of prototype construction, with the part of visibility and conferences (EHW, 2021). The main objectives are:

- Bring together the best university teams
- Create a hyperloop ecosystem
- Change the idea of hyperloop to a more forward-looking approach
- Challenge the teams to more ambitious goals.

European Hyperloop Development initiative

Hyperloop Development framework supports the "road to market" of a disruptive European initiative (European Commission, 2020b) to increase efficiency, availability, and sustainability of the current transport network.

Zeleros Hyperloop launched in 2018 a hyperloop development framework initiative with a starting budget of 100M€ and a 12 years timeframe to support the road to market of hyperloop in Europe to increase efficiency, availability and sustainability of the current trans-European transport network (TEN-T). The objectives of the framework are to support medium- and real-scale test-track development, ensuring safety levels and reduction of infrastructure complexity are met. The final goal is to achieve the needed scalability for long-distance routes in Europe and globally so society can benefit from the system. It includes the following projects:

- Hyperloop Subsystem laboratory validation: the project started in 2018 with regional, national and European grants from the R&D programmes and has as an objective to test the critical hyperloop systems in laboratory conditions. Linear motors, magnetic levitation, energy storage systems, aerodynamic propulsion and braking capabilities have been tested so far thanks to this programme. So far 10M€ have been invested in this programme.
- Hyperloop e-Mobility Hub: public-private partnership with a 5 year budget over 100M€ to build in Europe the needed capabilities for real-scale manufacturing and testing of hyperloop vehicles. The project is ongoing and open for European and international stakeholders, and it has received institutional support from Generalitat Valenciana and more than 20 European private companies and research centres to date.

- European Hyperloop Development center: the project promotes the creation of a test-track of 3km to be located in Spain to test at medium scale hyperloop systems at high speeds. The project is in planning stage and has received interest from public and private organisations.
- Real-Scale Hyperloop Certification center: the project consists in the creation of a commercial-scale hyperloop test-track to be able to certify the system at l scale. The project budget exceeds 100M€ and public-private partnership is required, with a horizon of 2030 to fulfil all required tests for commercial hyperloop operations and starting route deployment phase.
- Hyperloop Standards, Certification and Regulations project: with the standardisation and regulations process of hyperloop providing a technical implementation framework to support the technological development with the goal of converging to a common hyperloop solution.

European Hyperloop Program
R&D Program broadly supported by public and private sector to develop hyperloop and associated components, culminating in a test track for demonstration and certification to allow commercialization. The goal of the European Hyperloop Program (European Commission, 2018), initiated by Hardt, is to collaborate with hyperloop companies and co-developing partners in a common standardization roadmap, to bring down the costs of hyperloop through R&D, and to test and showcase the developed technologies to allow commercialization. The program will span several institutes and R&D centres in Europe, and is supported by a combination of industrial partners, research institutes and public bodies.

Most fundamental technologies required for hyperloop have an equivalent in either the rail (maglev) or aviation sector, but the integration of the technologies and several innovations in control systems, and lane switching, and boarding procedures still carry technological risks. The risk also exists that hyperloop will not find its way in policy and it may not be implemented. Finally, a non-European solution may get to market first, diminishing the effectiveness of the European program.

CEN-CLC/JTC 20 - Hyperloop systems
Standardization of all systems, products, services, and applications related to the hyperloop transport system (CEN, 2021). The Chairmanship of CEN-CENELEC/JTC 20 is hold by Spanish maglev and ERTMS expert Mr. Jaime Tamarit (Spain) and the proposal for the creation of the CEN/CENELEC JTC was put forward by Spanish UNE and Dutch NEN normalization agencies in 2019 with the support of organisations such as Zeleros, Arcelormittal or SEOPAN, among others (UNE, 2020a).

Hyperloop Connected
Hyperloop Connected (Hyperloop Connected, 2021) was built by Delft Hyperloop, together with other hyperloop teams, to solve problems encountered in the technological development. Currently, there is no comprehensive overview of who is working on the hyperloop and what they are working on. As a result, the impact of the work is limited. Some companies are hesitant to share their intellectual property with the rest of the world. To promote efficient work and to share Hyperloop knowledge, it was decided to launch Hyperloop Connected. The Hyperloop Connected includes:

- An interactive world map of all governments, companies, student teams and university staff working on hyperloop
- Vision articles from inspiring organisations, companies, universities, and students
- Tech articles from Hyperloop teams and companies
- The basics on the hyperloop so anybody can understand how it works
- Contribution to the development of hyperloop technology by sharing the knowledge acquired while working on a hyperloop team and uniting various parties.

MAFEX's Hyperloop Observatory
Mafex, the Spanish Railway Association, is the association that represents the Spanish railway industry, currently bringing together 94 companies that account for 82% of rail exports in Spain (MAFEX, 2021). The Association created the Hyperloop Observatory in 2019 (Vialibre, 2019) in with the main objective of analyzing how the Spanish railway ecosystem can boost the implementation and development of hyperloop.

- The observatory intends, on the one hand, to promote the capabilities of the Spanish railway sector, identify the research and development area to provide high-tech and innovative solutions to the different challenges, as well as support the legal framework that make its implementation possible.
- On the other hand, through the proven experience of the Spanish railway sector, it is intended to analyse the innovative technologies that improves the safety and security of all the system as well as promoting the interoperability.

The following organisations are involved (Hyperloop Observatory, 2021): Amurrio, Arcelormittal, Bombardier, CAF, Cetest, Comsa, Idom, Indra, Ingeteam, InseRail, MTC Wabtec, Revenga, Segula Technologies, SENER, Talgo, Thales, Tria, Typsa and Zeleros.

Railway Innovation Hub's Hyperloop Strategic Working Group:
Railway Innovation Hub is the Spanish non-profit Spanish innovation cluster in railway mobility made up of 85 companies that cover the entire value chain of the railway sector. Its mission is to boost technology and knowledge of the sector through the generation of collaborative projects. The organization created together with Zeleros one of the world's first platforms for impulsing hyperloop standardization works and technology working groups, involving leading railway and related hyperloop promoters (Railway Innovation Hub, 2019b) that nowadays involves the following organisations: Arcelormittal ,Abengoa, Actisa, Akka, Ayesa, Cloud Global, Eurogestion, Ferrovial, Gesnaer, Ineco, Inhiset, Sacyr, Schneider Electric, Tecnalia, Fhecor, Zeleros, Htt, Sdea, Sener, Revenga, Datlight, Eurecat, Uma and Thales (Railway Innovation Hub, 2021).

6.4. Hyperloop testing facilities and test-tracks

An overview of the current status of development of pods, tube systems and testing facilities for hyperloop is provided to complete the identification of active actions in terms of available infrastructure and test locations. Since the first introduction of the concept with the release of the Alpha paper (SpaceX & Tesla, 2013), significant progress has been made in the development and testing of subscale Hyperloop pod prototypes, having several institutions participated in the

Hyperloop Pod Competition (Wikipedia, 2021a), which was held in the facilities of SpaceX from 2017 to 2019. On a 1.2 km long, 1.83 m-diameter test track, the main target of the competition was to accelerate the development of Hyperloop, and to challenge student teams from all over the world to build transport pods, by demonstrating the technical feasibility of their concepts taking into account the performance and the potential to scale up their technologies to a full-scale hyperloop vehicle.

Hyperloop companies and organizations, which are involved in the development of pods and tube systems for the commercialization of hyperloop, are mentioned below as “developers”. Identifying the design issues, proving the feasibility, creating a scalable system and investigating potential ways to reduce the overall infrastructure and operational costs, are some of the key aspects to create small-medium testing facilities. A number of privately funded companies and public institutions have already constructed such facilities, aiming to develop full scale testing facilities. However, only one developer (i.e., Virgin Hyperloop One) has introduced pod and tube infrastructure in a passenger-scale test facility, and in November 2021 tested the world’s first passenger journey.

Due to continuous and strong interest in hyperloop systems, governments consider the implications and opportunities for its deployment, including technology governance, legislation, regulations, and government involvement (AECOM, 2020). In Europe, there is a strong public-private collaboration dedicated to the development of non-profit European Foundations to create testing facilities that will enhance the research and development of sustainable low-pressure transport technologies.

Table 3 summarizes the current status of the progress of different developers regarding their testing track facilities, the various scales, their technology and the maximum reported speed of the pods.

Table 3. Current status of the development of hyperloop testing track facilities in different scales

Name	Location	Max. Tested Speed (km/h)	Propulsion	Levitation	Testing Track Facilities
Hardt [1,2,3]	The Netherlands	-	LSM	EMS	Completed length 30 m, diameter 3.2 m
HyperloopTT [4,5,6,7,8]	France, USA, UAE, Germany	-	LSM	EDS	Completed in France-length 320 m, diameter 4m Developing in UAE-4.8 km passenger track & test track 1 km, in USA-multiple routes under study, in Germany-100 m cargo route
KRRI [9,10,11]	South Korea	1019	LSM	EDS	60 meter track, 20-30cm vehicles
Nevomo [12,13,14]	Poland	50	LSM	EDS	Completed- length: 48 m Developing - length 500 m
SouthWest Jiaotong University [15,16]	China		Unknown	HTS EDS	Completed: Circular test track in 2014 Developing: 1,5km test track 3m diameter for 1500km/h testing
SwissPod [16,17,18,19]	Switzerland	-	LIM	EMS	Developing- 40 m length
Transpod [20,21,22]	France, Canada	-	LIM	EMS	Completed at Developing at 3 km, diameter 2m
Virgin Hyperloop One [23,24,25]	USA, Saudi Arabia, India	387 -Devloop 48 m/s- Passenger Test	LIM	EDS	Completed in USA- length 500 m, diameter 3.3 m, Developing full scale projects in USA, Saudi Arabia and India.
Zeleros [26,27]	Spain	-	Compressed air Electric-Aerodynamic	EMS	Completed: 6 key subsystem prototypes. Developing: 3-4 km tube test-track for system integration at high speeds. 20-40km track for commercial certification and manned tests by 2030. Facilities for industrialisation of vehicle manufacturing and testing.

[1] (Degeler, 2020), [2] (Hardt, 2019b), [3] (Delft Hyperloop, 2019a), [4] (HyperloppTT, 2021), [5] (HyperloopTT, 2019), [6] (HyperloopTT, 2021c), [7] (HyperloopTT, 2021b), [8] (Taub, 2020), [9] (Cuthbertson, 2020), [10] (Min-Hee, 2020), [11] (Gantner Instruments, 2021), [12] (Todd, 2019), [13] (Nevomo, 2020), [14] (Gooch, 2021), [15] (Sokol, 2014), [16] (Weixin, 2020) [17] (Uta, 2020), [18] (AECOM, 2020), [19] (Bradley, 2020), [20] (Timperio, 2018), [21] (Transpod, 2021b), [22] (Transpod, 2021a), [23] (Transpod, 2021c), [24] (Virgin Hyperloop, 2021a), [25] (Virgin Hyperloop, 2021b), [26] (Hawkins, 2020), [27] (Zeleros, 2020), [28] (European Commission, 2020b)

6.5. Transport community

The hyperloop has triggered global awareness and efforts between 2015 and 2020 on improving its systems and components. A review of the existing literature is performed to explore the stakeholders involved and identify the transport community and its interactions between companies, transport systems. The review may also serve as a guide to stakeholders in EU (private and public organizations) in interacting with other interested parties.

The literature review focused on publications on academic journals and conferences, and reports in English language. A search was performed by using the term "hyperloop" and "tube transport". In total 91 documents were identified; 72 resulted by using the term "hyperloop" and 19 by using the term "tube transport". Literature has been published from 2008-2021 (i.e., first quarter of 2021) with the majority of them (95%) being published after 2016 as shown in Figure 8, which shows the interest in hyperloop mode after the release of Hyperloop Alpha by Elon Musk in 2013 (SpaceX & Tesla, 2013). All publications before 2014 refer to "tube" transport or "vactrain".

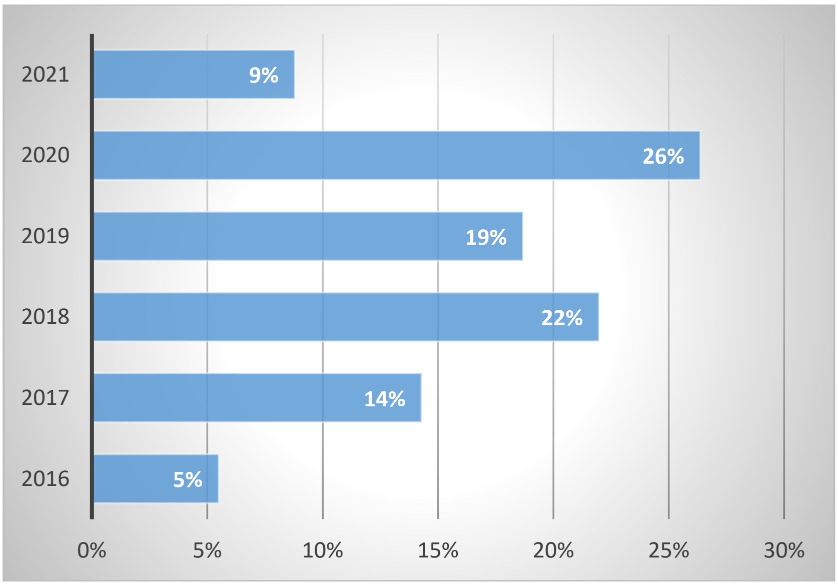


Figure 7. Percentage of publications year for hyperloop literature.

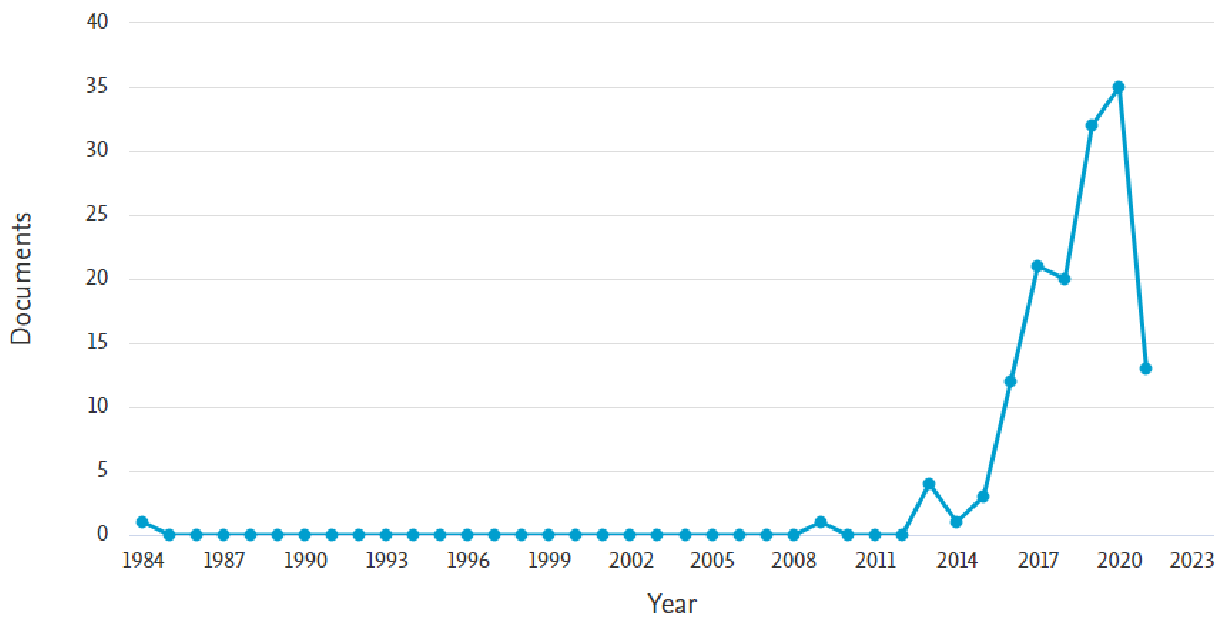


Figure 8. Publications year for hyperloop literature at SCOPUS DataBase (30 April 2021)

Half of the literature at global level refers to scientific journals while the remaining 50% is almost equally distributed between conference publications and reports (**Error! Reference source not found.**).

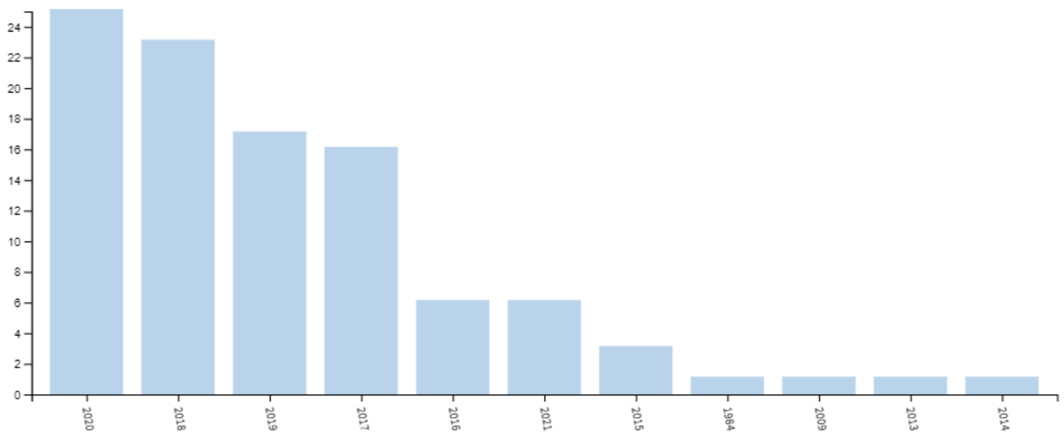


Figure 9. Count of publications with the word Hyperloop search in Web of Science Database review in 30april 2021

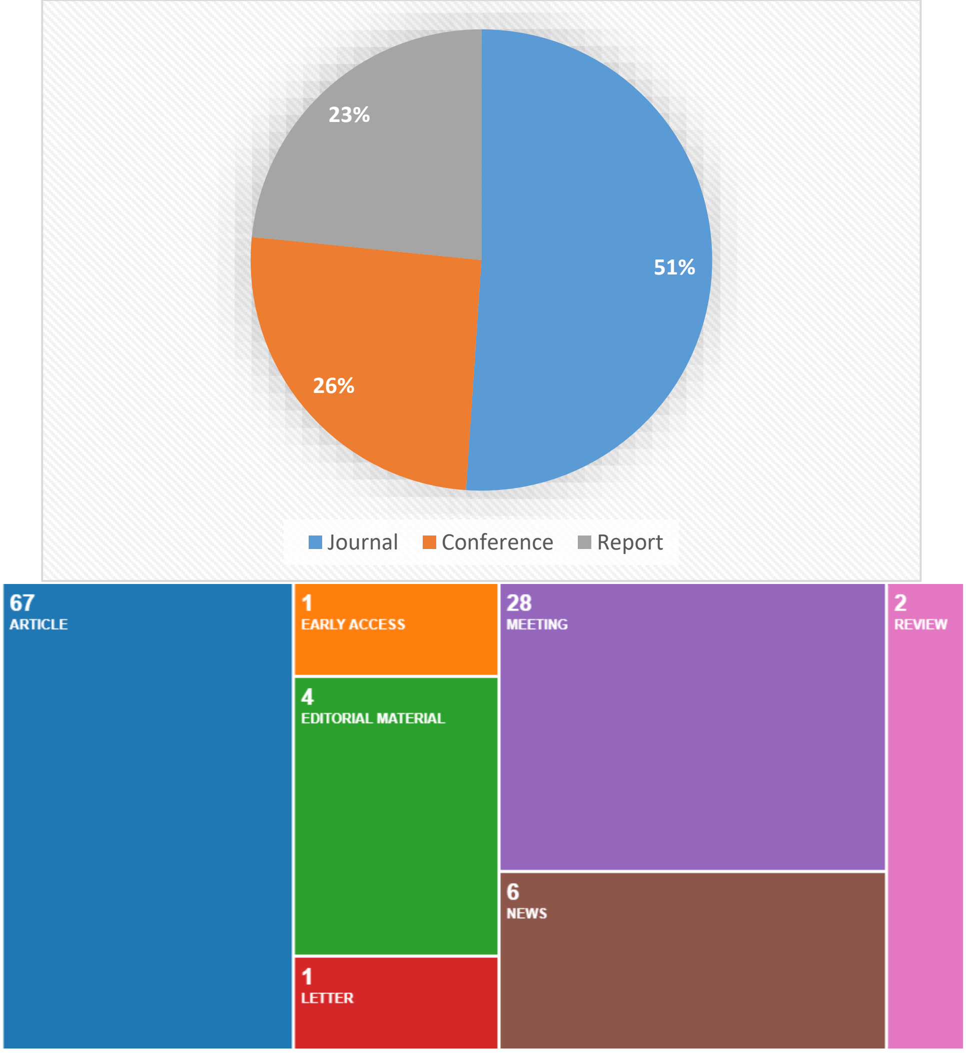


Figure 10. Hyperloop publication search in Web of Science Database by type review in 30april 2021.

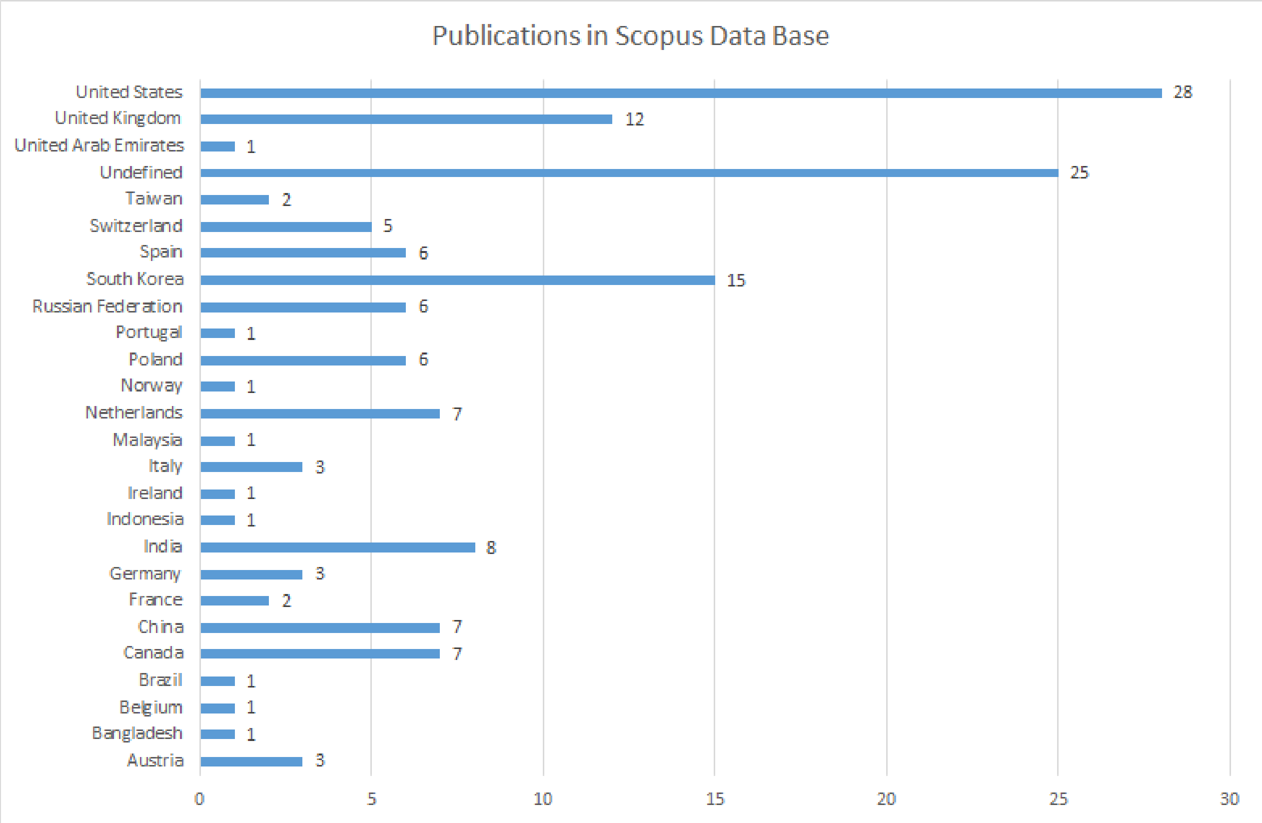


Figure 11. Publications about Hyperloop in SCOPUS Data Base by country.

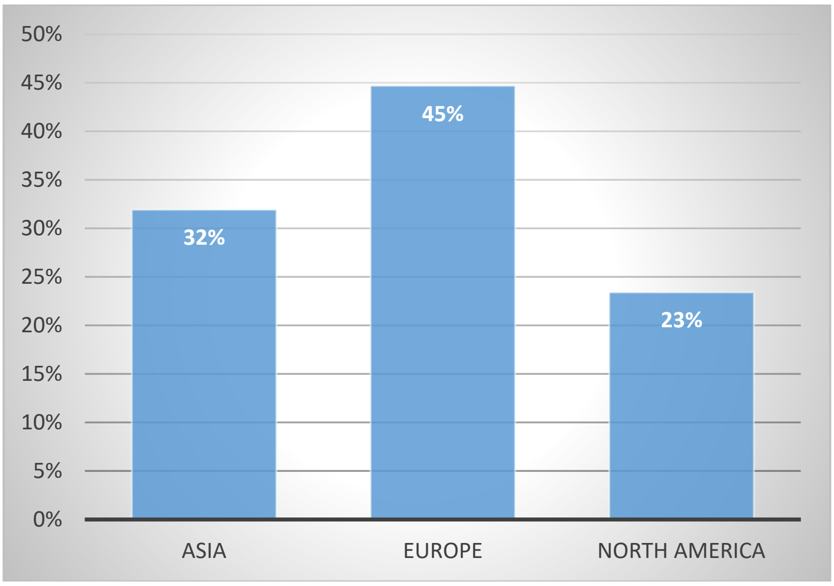


Figure 12. Hyperloop publications by geographic area

In an attempt, to map the geographic location of these publications on hyperloop, all authors have been recorded by country and aggregated by continent. Europe contributes significantly to hyperloop research as shown in Figure 12 with 45%. The remaining percentage of 55% is allocated to N. America (23%) and Asia (32%). A summary of all hyperloop studies in Northern America and Asia is presented in Annex. The table presents a detailed categorization of publications per location, infrastructure and pod components, as well as performance areas. This categorization allows to obtain the required information and insights related to hyperloop system and its components that stakeholders aim for, when developing a hyperloop system and identifying the research trends on this emerging fifth mode of transport.

Several academic and industrial research teams that focus specifically on the hyperloop system and its components, have started to form at global level. Other transport stakeholders are also engaged in hyperloop research occasionally and publish their work on this developing field. Academic organizations collaborate usually with governmental and industry partners. These academic organizations do not focus exclusively on hyperloop; rather their activities relate to hyperloop components and conduct occasional research on hyperloop aspect. However, as it was presented in section 6.1, some university-based teams have been developed that focus exclusively on hyperloop. Non-EU based organizations are presented in Annex. The list presents the diversity of university disciplinaries that are engaged to research activities related to the hyperloop, with 80% of them being a university or a research centre.

Focusing on Europe and the stakeholders in this area, a further analysis is performed. Due to difficulties to aggregate available data for all fields of interest and stakeholders, we present collected data. The analysis considered the publications in the literature as well as stakeholders that have presented in previous sub-sections. It was estimated that 45% of the publications were found to be released by a European based organization, from which 48% were released in a scientific journal, 21% as a conference publication and 31% as a report. The majority of all published material (86%), including, journals, conference publications and reports, in Europe has been released by academic institutes.

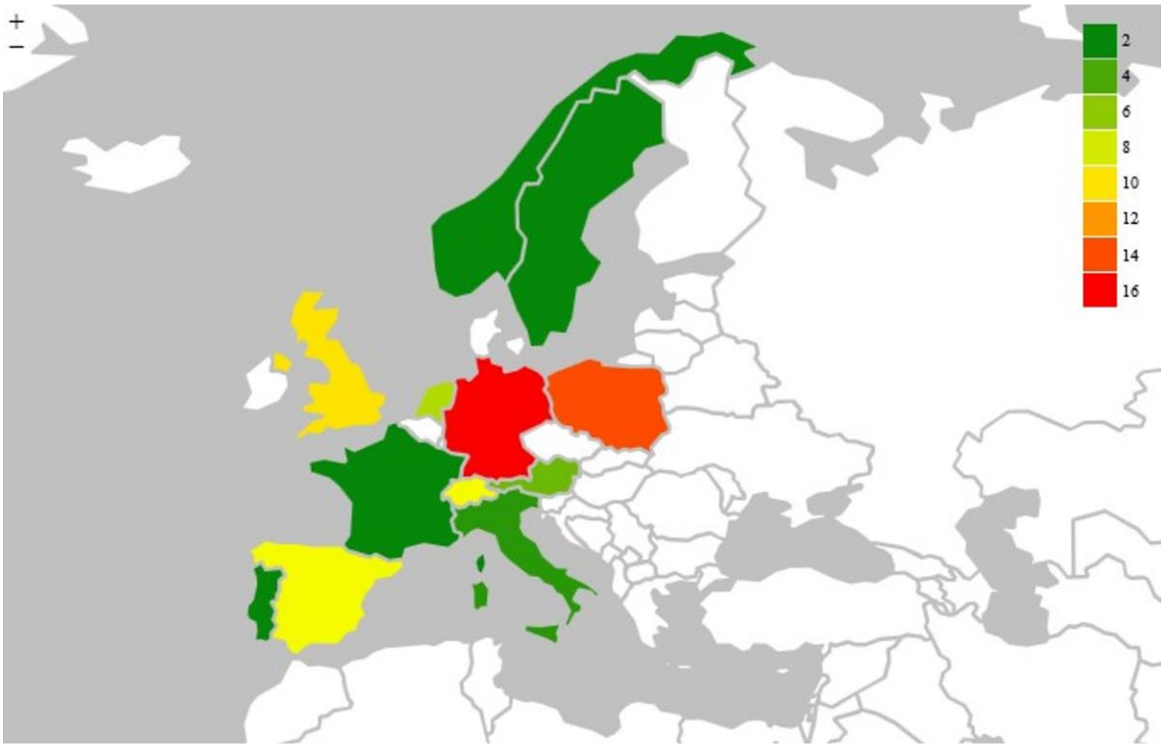


Figure 13. Distribution of countries working on hyperloop

According to literature review shown in Table 4, in total 61 unique organizations have been identified in 13 EU countries. It should be noted that different departments in a few organizations are related to hyperloop, however, these occasions are counted as single entries. Figure 13 and Figure 14 show the percentage of entries per country, with Germany, UK, Spain, and Switzerland accounting for 24%, 15%, 13% and 13%, respectively. All other countries, are allocated a share of 10% or below.

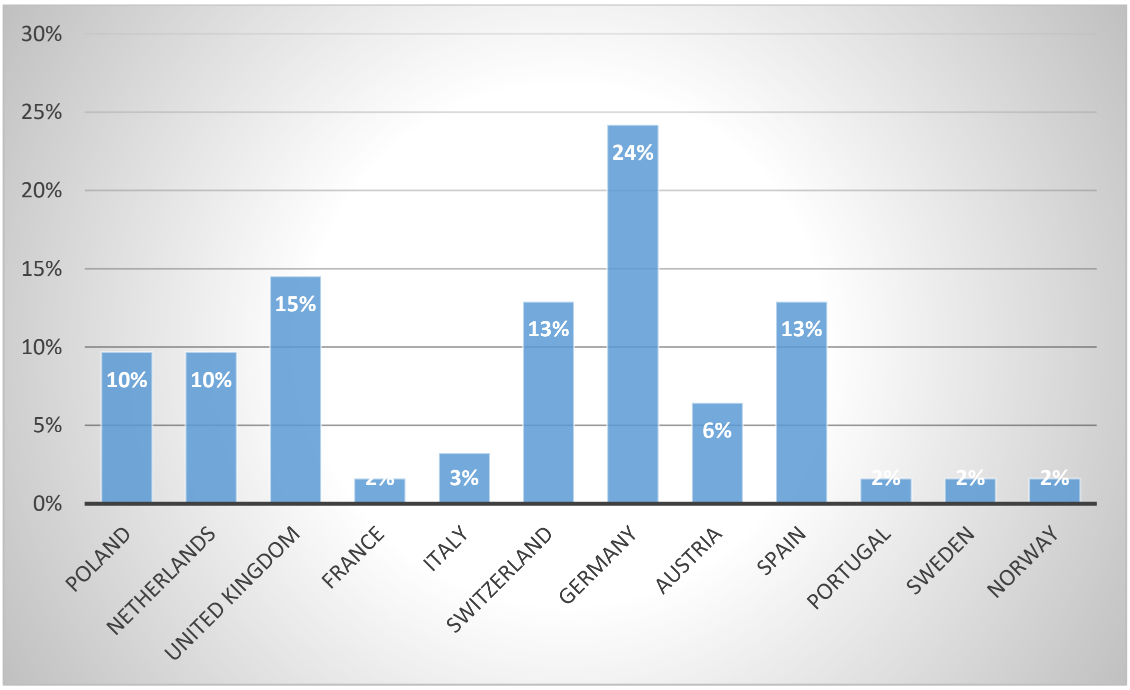


Figure 14. Stakeholder percentage related to hyperloop per country

The majority of EU based organizations that are related to hyperloop, are found to be academic or research institutes, whereas, only 13% and 7% of them are industry and non-profit organizations (Figure 15)

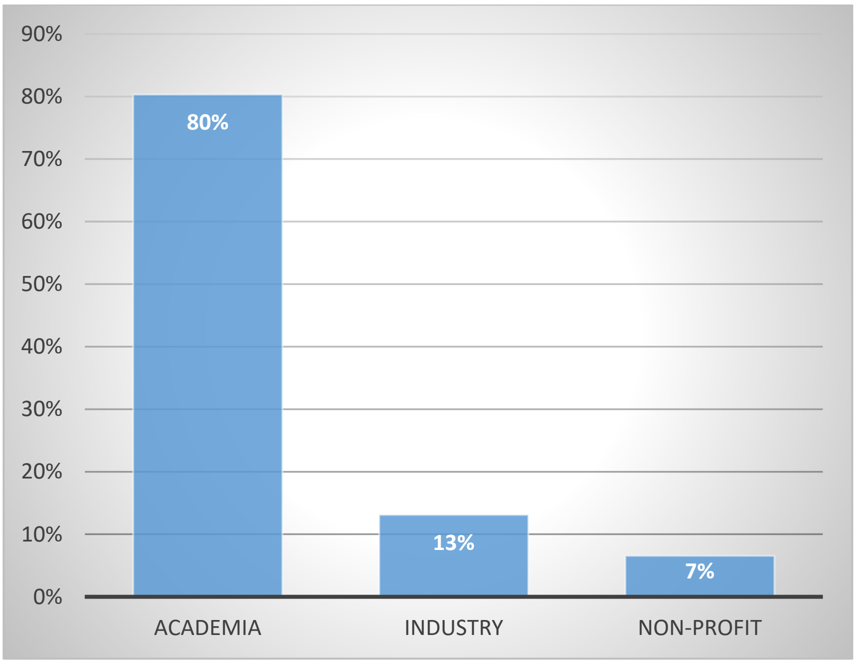


Figure 15. Hyperloop stakeholders per principal field.

In terms of publications by European organizations, almost half of the publications are journal publications (48%) and 22% are conference publications, showing the academic interest related to the hyperloop system and the increasing research attempts in different aspects of the system. The remaining 31% is allocated to reports, which are associated mostly to industry-based stakeholders.

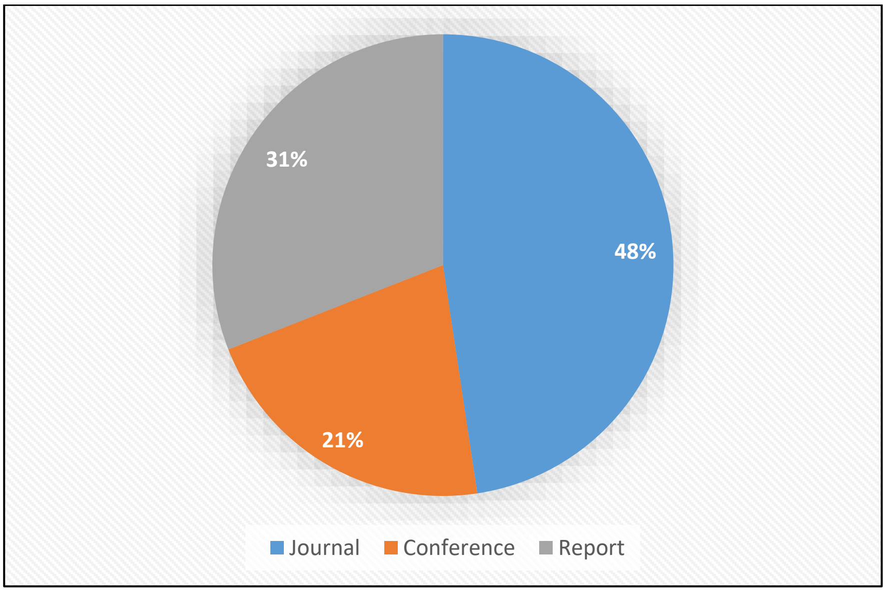


Figure 16. Hyperloop EU publications by type

An analysis of published literature is performed on the basis of infrastructure, pod and performance to gain a deeper insight on the hyperloop components and performance goals that that stakeholders work. Infrastructure is divided into the: 1) Tube, 2) Substructure, 3) Interface pod-tube, 4) Station, and 5) Other. “Other” covers publications that focus on other aspects or on generic hyperloop infrastructure aspects. The pod is divided into: 1) System and propulsion, 2) Interior, and 3) Both. Finally, the performance of the hyperloop system is explored by considering six areas: 1) Safety, 2) Energy, 3) Aerodynamics, 4) Traffic and capacity, 5) Environment, 6) Cost, and 7) Other. “Other” refers to performance aspects that are not covered within the six areas. Publications that focus on legislation were considered separately; a necessary area of research for the development and establishment of hyperloop system. Figure 17 summarizes the results of this analysis. It is noted that one publication may fall to one or more of the defined areas, therefore the total sum may not be 100%.

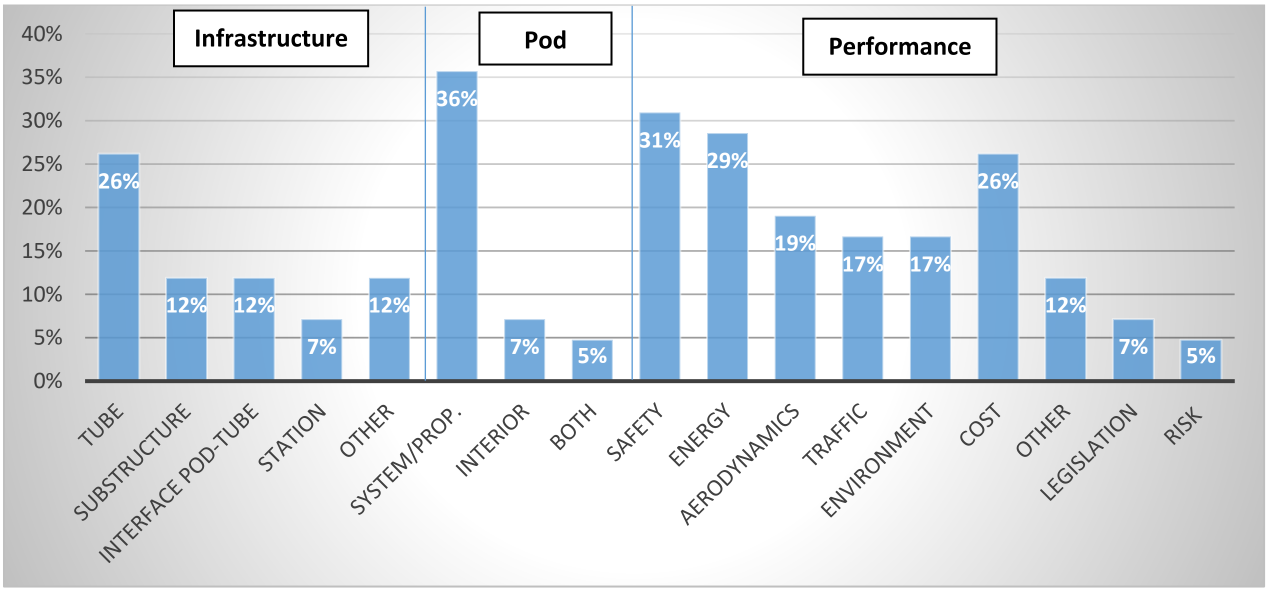


Figure 17. Hyperloop EU research areas

Hyperloop studies are found to conduct research related to the traction of the pod (36%) within the tube (26%) and quantify impacts related to safety (31%), energy (29%) and cost (26%). Other hyperloop areas include passenger comfort and system acceptance while focusing on substructure and station, is scarcer in the EU literature. For the organizations that focus on the hyperloop pod, the majority of them focus on the exterior design (i.e., related to aerodynamics), whereas only two studies were found to focus specifically on the interior. Other fields of research are related to social impacts, land implications, serviceability, and hyperloop maintenance.

Different fields of research are engaged to hyperloop system, including mechanical, transport, electric and aeronautical engineering as well as business and structural experts. In terms of transport modes (when such information was available), 7% of EU entities relate to aviation, 44% relate to high-speed rail, 25% relate exclusively to hyperloop and 24% relate to road as shown in Figure 18.

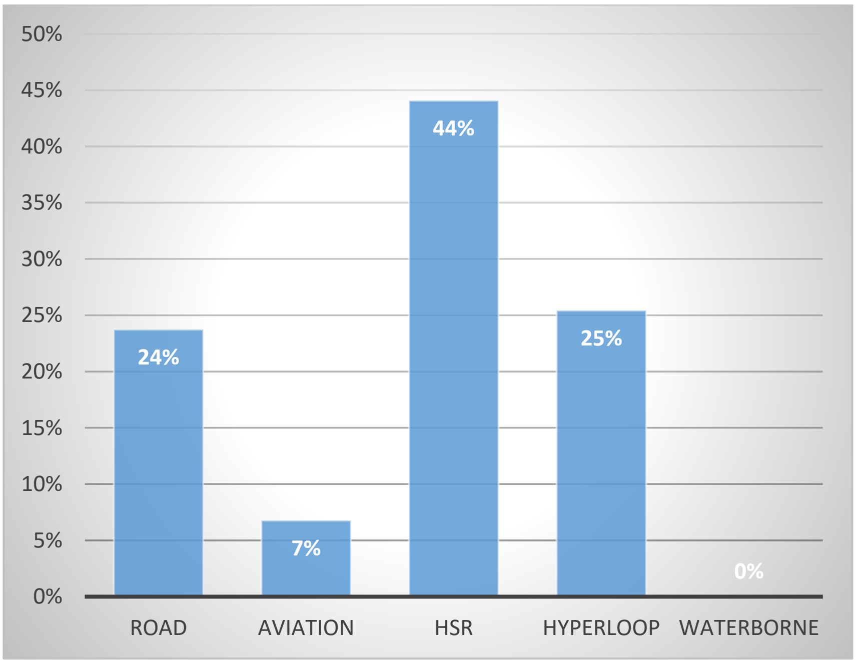


Figure 18. EU Stakeholders' involvement to other transport modes

The review serves as a guide to stakeholders and investors in seeking partnerships and establishing research collaborations on hyperloop. Moreover, the review highlights the gaps that exist in research areas in the development of hyperloop. A comprehensive literature review of hyperloop is presented in Table 4, highlighting the major infrastructure, pod and performance aspects studied.

Table 4. Hyperloop publications in Europe

Source	Country	Type	Infrastructure	Pod	Performance	Comments
(Stryhunivska et al., 2020)	Poland	J	Station		Safety	Analysis of a designed underground station infrastructure
(van Goeverden et al., 2018)	Netherlands	J			Other	Financial, social/environmental indicators.
(Nowacki et al., 2019)	Poland	C	Tube		Energy	Study the flow of the capsule, including the determination of the force acting on the nose of the capsule.
(Walker, 2018)	United Kingdom	R	Other	Interior	Other	Construction tube and substructure. Performance: travel time; capacity; land implications; energy demand; costs; safety; and passenger comfort
(Janić, 2020)	Netherlands	J			Environment	Energy consumption and GHG emissions

Source	Country	Type	Infrastructure	Pod	Performance	Comments
(Alexander & Kashani, 2018)	United Kingdom	J	Substructure		Other	Simulate the dynamic response of continues bridges (safety)
(Connolly & Woodward, 2020)	United Kingdom	J	Tube	System/prop.	Aerodynamics	Energy, safety, economics, journey time
(Riviera, 2018)	Italy	R	Other	System/prop.	Energy	Tube, substructure, station
(BAK Economics AG, 2020)	Switzerland	R			Other	Travel time, speed, cost, capacity, energy, environment, safety
(Doppelbauer, 2013)	United Kingdom	R	Other	System/prop.	Other	Summary of hyperloop system Questions and practical application. Fundamental aspects related to innovation in infrastructure networks are discussed.
(Gkoumas & Christou, 2020b)	Italy	C				Interactions with other modes, current status in EU and risk assessment discussion
(Hansen, 2020)	Netherlands	J	Station	Interior	Other	Technical feasibility of the proposed Hyperloop concept for vehicle design, capacity, operations, propulsion, guidance, energy supply, traffic control, safety, alignment, and construction are discussed in more detail. Environmental impacts and uncertain investment, operating and maintenance costs for implementation of a hyperloop line are described.
(Munich RE, 2017)	Germany	R				Risk assessment
(Tudor & Paolone, 2019a)	Switzerland	C		System/prop.	Energy	Optimal design of the propulsion system of an energy-autonomous Hyperloop capsule.
(Ahmadi et al., 2020)	United Kingdom	J	Substructure		Safety	Exploring the lateral dynamic interaction of bridge deck (twin tube) and piers
(Voltes-Dorta & Becker, 2018)	United Kingdom	J			Traffic	Planning as a complement to airport
(Gkoumas & Christou, 2020a)	Italy	J	Other	System/prop.	Other	Energy consumption, safety and serviceability, and financial feasibility. Literature review aspects.
(Nick & Sato, 2020)	Switzerland	J	Tube	System/prop.	Aerodynamics	Drag and lift forces
(Gkoumas & Christou, 2021)	Italy	J	Other	System/prop.	Other	Safety and serviceability performance.

Source	Country	Type	Infrastructure	Pod	Performance	Comments
(Li et al., 2019)	Netherlands	C		Interior	Other	Embarking and disembarking process for the hyperloop. Higher efficiency and better user experience.
(Wong, 2018)	Netherlands	R	Tube		Aerodynamics	Aerodynamic shape optimization procedure for a hyperloop pod.
(HYPED, n.d.)	United Kingdom	R			Cost	Feasibility study, cost, social, environmental impacts.
(Tudor & Paolone, 2019b)	Switzerland	C	Interface pod-tube	System/prop.	Energy	Assessment of the optimal design of the propulsion system of an energy autonomous Hyperloop capsule supplied by batteries.
(Schodl et al., 2018)	Austria	C			Other	Regional impacts: social, cost, environment.
(Munir et al., 2019)	United Kingdom	R		System/prop.	Cost	Sustainability study.
(González-González & Nogués, 2017a)	Spain	R				Review general concept.
(González-González & Nogués, 2017b)	Spain	R			Cost	Comparison table HSR, Maglev, and hyperloop
(Werner et al., 2016)	Germany	J			Other	Speed, frequency, payload, energy, consumption, safety, traffic, noise, reliability, pollution, cost, maintenance, shared value.
(Delft Hyperloop, 2020)	Netherlands	R	Tube	Both	Safety	fire safety, the communication system, perceived safety and emergency evacuation.
(Delft Hyperloop, 2019a)	Netherlands	R	Other	Both	Safety	Levitation, propulsion, passenger pod, tube, vacuum, pod, communication, artificial Intelligence, cost estimation, safety.
(Connolly & Costa, 2020)	United Kingdom	J	Substructure		Safety	Simulating ground-wave propagation in the presence of a series of discrete high-speed loads moving on a soil-guideway system.
(Strawa & Malczyk, 2019)	Poland	J	Interface pod-tube	System/prop.	Other	Performance and stability of the vehicle as well as ride comfort of passengers travelling in a compartment.
(Machaj et al., 2020)	Poland	J		System/prop.	Aerodynamics	Aerodynamic and heat transfer study of a battery

Source	Country	Type	Infrastructure	Pod	Performance	Comments
						powered vehicle moving in a vacuum tunnel.
(Lluesma-Rodríguez, Álcantara-Ávila, et al., 2021)	Spain	J	Tube		Aerodynamics	Use methods for extensive direct numerical simulations of passive thermal flow for several boundary conditions
(García-Tabarés et al., 2021)	Spain	C	Interface pod-tube	System/prop.		Studied and compared alternatives for acceleration
(Lafoz et al., 2020)	Spain	J	Interface pod-tube	System/prop.	Energy	Analyses the alternatives for the power supply of hyperloop. Selected to study the technology case of the Spanish company Zeleros.
(Museros et al., 2021)	Spain	J	Substructure		Safety	Obtain representative values of the main internal forces and stresses leading to a preliminary design of the vacuum tube. Two basic configurations based on steel tubes are proposed. The strength and stability of the tube have been analysed by taking into account the self and dead weight, internal low pressure, wind, thermal and traversing vehicle dynamic effects.
(Pellicer Zubeldía, 2020)	Spain	R	Tube	System/prop.	Other	A freight transport vehicle has been conceptually developed, analysed and simulated. Established variables for the different aspects: Kantrowitz limit, aerodynamics, transportation, energy consumption, batteries, levitation and propulsion, etc.
(Lluesma-Rodríguez, González, et al., 2021)	Spain	J	Tube	System/prop.	Aerodynamics	Demonstrated that the drag coefficient is almost invariant with the pressure conditions.
(Vellasco, Bruno Quilici et al., 2020)	Spain	C			Other	Analysed existing infrastructure network of Kazakhstan, highlighting the constraints and difficulties. Reviewed aspects of the proposed corridor from a technical, social, economic, and environmental perspective.

Note: Journal (J), Report (R), Conference (C).

7. Legislation and Funding

Development of alternative technologies, such as the hyperloop, presents a series of challenges that are not only technological. It should be taken into consideration that the development of very high-speed transport systems also implies the management of legal aspects in which the safety of users and facilities must prevail over any other element. The European Union's commitment to the development of new transport technologies allows working on a regulatory framework that guarantees compliance with safety and service requirements that are currently applied to other transport methods. Until all hyperloop challenges are defined, it will be difficult for countries to establish a hyperloop focused legislation. According to Leibowicz (Leibowicz, 2018), these kinds of decisions should not be made until the technologies are proven.

Although there are other transport sectors with similar characteristics based on which the hyperloop may be supported; some aspects of hyperloop differ substantively. For example, the hyperloop uses a propulsion system similar to the maglev trains but runs on higher speeds. Also, the pressure value that the pod supports may be similar to conditions used in airplanes or aircrafts.

In this sense, several participants of the HYPERNEX project have been involved in recent years in R&D programs that have had both public and private funding. The funding received has made it possible to establish a working environment between promoters and academics that will allow the development of the different solutions proposed within the same regulatory framework. The definition of hyperloop as an autonomous long-distance transport system imposes supranational challenges that must be faced too. The European Union helps in this regard with the generation of common standards for the entire territory, promoting interoperability between systems and reducing the competitive advantages that certain local legislation may entail.

7.1. Legislation

The hyperloop as an autonomous vehicle (EUR-Lex, 2018), must be aligned with the EU strategy for future mobility and address the different issues derived from security, responsibilities, data management, infrastructure and ethical issues that may arise. European policies and laws related to autonomous and connected transport should cover all modes of transport, including short sea shipping, inland waterways, freight drones and light rail systems. This requires the establishment of coordinated international standards to ensure security and interoperability across borders. Black boxes will be mandatory to improve accident investigations and responsibilities definition. Ethical issues and data protection must be developed quickly to improve the trust of citizens. Accessibility for people with reduced mobility is considered a matter of special attention.

The European Commission's Directorate-General for Mobility and Transport (DG MOVE) has held numerous workshops over the past years with hyperloop companies as well as regulatory authorities and standards bodies leading to the establishment of a baseline for the functional blocks of a hyperloop system and safety requirements. In December 2020, the European Commission has included hyperloop as an emerging technology within the 'Sustainability and Smart Mobility Strategy', has committed to support facilitating testing and trials and to provide a regulatory framework towards the future deployment of this technologies onto the market.

One of the biggest milestone reached at the European level so far has been the creation of a joint committee (JTC 20), which was promoted mainly by the Spanish Association for Standardization (UNE) (UNE, 2020b) and the standardization body of the Netherlands (NEN) in October 2020.The CEN-CENELEC/JTC 20 (CEN, 2021) 'Hyperloop systems' committee focuses on the standardization regarding safety and interoperability, and specifically association of European standards developed for other transport systems. The CEN-CENELEC organizations will be ultimately in charge of generating and adapting the new standards that allow to introduce into the market safe hyperloop systems and try to achieve the maximum possible interoperability of services throughout Europe, mainly seeking the functionality of the service and its operability at continental level. In parallel, the US Department of Transportation has developed a working document, published in January 2021 (NETT Council, 2021), commissioned by the Volpe National Transportation Systems Center in order to evaluate the hyperloop standardization activities, establish a common framework for future standardization and identify the perspectives of interested parties in the applicability of existing standards.

The two-ways collaboration between regulation and standardization actors is a key point to make hyperloop transport a reality and to grant safety, interoperability, security and intermodality since de design stage.

The following sub-sections focus on the legal aspects that must be considered during the development and implementation of the hyperloop.

7.1.1. Safety and security

So far, a regulatory framework that focuses on safety and security for hyperloop passengers does not exist. The protocols applied in railroad or airlines can be used as references, but differences with respect to other modes must be considered in the final operating terms. Regarding air transport, the main difference in the case of the hyperloop is that routes are pre-defined, restricting the possibility of traffic reorganization. With respect to railway, the main difference lies in the way passengers are transported. In this sense, the pressurization of the cabin is essential due to the special conditions of movement through the infrastructure.

These fundamental differences make it possible to characterize the hyperloop as a critical transport system. The hyperloop may open up a range of external possibilities that should be considered in case of failure. This is why the main obstacle faced by national and international governments, construction and infrastructure management companies, is the generation of a regulatory framework and a set of laws. These should be capable of reaching a level safety of at least the same structural strength as the existing benchmarks at the railway and air navigation level. It is clear that there is a long way to achieve these goals for hyperloop. In relation to security, the technical operating characteristics of this transport system also imposes the need to establish new action protocols in the event of catastrophic failure.

The large number of safety and security variables that can compromise the operation of the system will require the management of a large amount of data linked to control and surveillance systems. In this sense, no in-depth studies have been carried out on the implications that these systems may entail, regarding the centralized control of infrastructures, which will sometimes be international in nature. At this point, HYPERNEX establishes itself as one of the first guides to plant the seed for the detection and development of the strictest and most efficient standards.

7.1.2. International travel

Distances for which hyperloop is considered to be competitive as a means of transport in the short term also impose a legal challenge when considering border crossing. There are valid references in this sense for its application in customs and immigration terms, with protocols of different nature being applied depending on the country of origin and destination.

On the other hand, the use of the infrastructure of each country usually requires the payment of a series of fees or payments to the organizations that manage them, which in the case of hyperloop will have to be set. This also establishes a logistic challenge within the hyperloop stations and terminals that work as an access door to a certain territory since it is not considered a border system in which the vehicle must stop to carry out inspections.

7.1.3. Legal framework of operation

As hyperloop is a completely new mode of transport, the identification of risks that may jeopardize security, in general terms, can open up a very extensive field of requirements.
In this sense, it is possible to start from the legal requirements in safety aspects that are imposed in other modes of transport, generating equivalent regulations but adapted to the specific operating conditions. The generation of new standards should be focused on mitigating risks before they appear. For example, there are currently legal requirements on the oxygen reserves that must be carried in planes, but this does not apply to any land transport system or any guided transport system.

The European regulation could be divided into four main areas of application as far as transport is concerned: road, rail, sea and air. Within these four groups, it is impossible to adjust the definition of hyperloop, which is why the need for a specific regulation becomes clear.

Given the current state of development of the hyperloop, with the implementation of the first small-scale functional prototypes, the identification of risks on which a regulatory framework must be established will begin to be increasingly dynamic, allowing the creation of a range of situations in which the governance of regulatory agents can mitigate or even eliminate them.

7.1.4. Interoperability, safety and standardization

If the railroad and its evolution in recent decades are taken as a reference, the interoperability at global level may be the simplest way to summarize most of the technological efforts made. The possible existing combinations between rolling stock, control systems, supervision systems, traffic management systems, etc. it is, by all accounts, infinite. If, additional problems within the same nation are considered then interoperability is more challenging. For example, in Spain the railway gauge varies between 1,668 mm, 1,435 mm and 1,000 mm.

In addition, we are referring to a new transport system, its safety when putting into the market is a real challenge. It shall be granted a safe fabrication, construction and deployment of the hyperloop system. On one hand, the requirements and characteristics of the products, their verification and testing and on the other a safe operation, including maintenance and emergency. Safety is the basis to set a reliable system for all stakeholders, from public authorities to end users.

A standard is a document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context (definition of the European Standardization Bodies, CEN and CENELEC). Standards are voluntary which means that there is no automatic legal obligation to apply them. However, laws and regulations may refer to standards and even make compliance with them compulsory.

It should therefore be considered that the hyperloop must begin from a safe and interoperable regulatory base, in which infrastructure or services dependent on the systems adopted are not existent. The standardization of components or communication protocols, for example, will ease the future implementation of this new transport system, opening the doors to a competent market in the technological field and the transport service. The use of work environments such as HYPERNEX allows generating meeting points for technological and regulatory developers, also taking advantage of the early stage of technology development to actively condition future advances in search of a common system.

7.1.5. Certification

The hyperloop certification, both at the component level, as well at the vehicle and the system level has been the subject of several recent studies. Authors emphasize on the use of current railway legislation as a basis for the development of an adaptation to the hyperloop.

In this regard, due to their applicability, technical specifications for safety and interoperability stand out both in relation to infrastructure and for rolling stock, signaling, electrification and operation of railway lines. In addition, standard EN 50126 does not require major adaptations to be able to be applied to new guided transport systems as well.

It should be emphasized again that guaranteeing safe operations must be the priority during the implementation of the hyperloop. To this end, the creation of international standardization and certification bodies will be an advantage in the final development of technological solutions. Many standards may be derived from those developed airplanes or railways regarding certification.

According to the report "The future of Hyperloop" from the University of Delft (2019) (Delft Hyperloop, 2019a), the most useful technical specifications for determining the hyperloop certification are those corresponding to:

- Control command and signalling
- Safety in railway tunnels
- Persons with disabilities and with reduced mobility

Certification is crucial to establish the security of the system. Two certification models can be established; one similar to that of airplanes (Aircraft) where there is a single organization, the European Union Aviation Safety Agency (EASA), responsible for the certification; or similar to the railway sector where there are multiple organizations that carry out the certifications (Notified Bodies). The option of a single certifying organization seems to be more accepted by the different agents that intervene in the hyperloop.

In addition, the certification approach is different for aviation and for railway. It has to be further studied the better approach. On one hand, the certification scheme used in aviation may be useful for the certification of the pod, on the other, the certification scheme used in railway may be the better option for the infrastructure, the interfaces and the communication aspects. This topic needs of further studies.

And finally, for the system verification and certification, a full-scale test track needs to be put in place. For this purpose, a European Test Track for certifying hyperloop is needed. Due to the fact that an important funding from the EC will be necessary, only one reference test track is assumed to be constructed. Because of that, different technologies should be analysed and compared; the development of the test track should be based on proven best solutions.

7.2. Funding

Given the current state of development of the different technological solutions and the independence existing between them today, it is possible to affirm that financing the implementation of the hyperloop as a transport system cannot be carried out unilaterally.

The use of a well-defined competition framework will encourage private capital investments, further strengthened by the connection to sustainable transport systems that make it possible to achieve the objectives of the 2030 Agenda.

One of the main drawbacks that arise for the installation of these new technologies is the user acceptance. This issue extends to the perception that investors and entities that intend to form part of the hyperloop ecosystem may have about the system (e.g., builders, managers and operators). The need for large investments in the early stages of implementation also conditions the future of this technology.

The Hyperloop White Paper "Hyperloop Alpha" (SpaceX & Tesla, 2013) suggests that a low-ticket cost will allow capital amortizations over 20-year terms for lines of 500 km in length and an estimated annual demand of 7 million passengers. This does not consider operating costs, but in any case, it seems that amortization can be easily achieved in reasonable time frames. Also, considering the international extension of hyperloop networks, it is difficult to assess the real economic involvement that public and private entities will have during the implementation of hyperloop.

In terms of costs, the increasing complexity of the systems that are identified and required to be installed, as well as the recent increase in the price of a multitude of raw materials, such as copper, makes it possible to assume that the cost estimates made prior to 2020 will be exceeded, expecting to double the amount initially estimated. Latest estimations place the approximate price around 29 million euros per kilometer (rreferring to on-board power supply solutions, such as for Transpod and Zeleros) (Transpod, 2017b), significantly reducing the competitiveness of this system compared to classic high-speed rail lines[3]. Estimation of operating costs is challenging. The limited information on actual operating costs, which generally differ significantly from those proposed theoretically, makes it impossible to consider an average rate.

7.2.1. Funding by the European Commission

Different European projects related to hyperloop have received funding from the European Commission:

- H2020 SME Instrument Phase 1 for feasibility analysis of hyperloop-based side products.
- Eureka Eurostars projects for the deployment of hyperloop side technologies in port applications.

In addition, the following investment projects can be found in the European Commission portal:

[3] As per PwC report (Armitt & Houghton, 2016) the European HSR standard cost is 36€M/km. Hyperloop costing 29€M/km would increase its competitiveness against HSR.

- the European Hyperloop Program (Investment Project EIPP-20180473) (European Commission, 2018) initiated by Hardt with € 4.5 million out of a total of €150 million. Its objective is to collaborate with hyperloop companies and co-developing partners in a common standardization roadmap, to bring down the costs of hyperloop through R&D and to test and display the developed technologies to allow its commercialization.
- The European Hyperloop Development Initiative (Investment project 20191248) (European Commission, 2019) promoted by Zeleros, with the objective of supporting the road to market of hyperloop in Europe and increasing efficiency, availability and sustainability of the current trans-European transport network (TEN-T). To achieve an interoperable system, the standardization process of hyperloop needs a R&D framework to support the technological development with the goal of converging to a common hyperloop solution. It includes the following projects:
    - Hyperloop Subsystem laboratory validation
    - European Hyperloop Development center
    - Real-Scale Hyperloop Certification center
    - Hyperloop e-Mobility Hub

Hyperloop Standards, Certification and Regulations project: in parallel, a project runs to support the standardisation, regulations and certification processes of hyperloop ensuring that the technical implementation converges to a common hyperloop solution. This includes participation at CEN/CENELEC JTC Level, Regulatory Roundtables and Certification forums and projects.
Most of these have been funded under the Horizon 2020 Programme. Horizon Europe (European Commission, 2021a) is a 95-billion-euro funding programme for innovation and research, that covers all major scientific and technological disciplines, and encourages collaborative projects (consortium) for a joint goal. Within this program specific points of interest are proposed for financing opportunities around the hyperloop. Specifically, within Pillar 2 "GLOBAL CHALLENGES & EUROPEAN INDUSTRIAL COMPETIVINESS" there is Cluster 5 (European Commission, 2021b) "Climate, energy and mobility". There will be a call that may arise multiple projects (Figure 19).

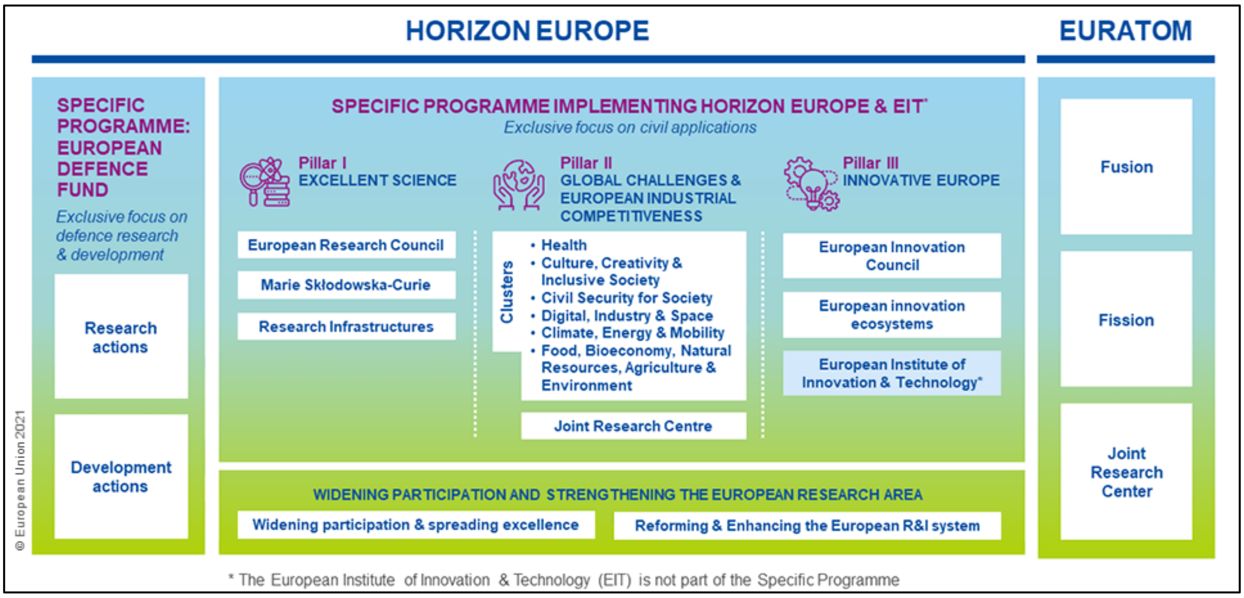


Figure 19. Horizon Europe Program

Transforming Europe’s Rail System Proposal for a European Partnership under Horizon Europe (European Commission, 2020a) gets conceptual inputs near to the hyperloop system, including an operational objective of the partnership to bring into market new land guided transport solutions: through concepts such as “pods”, “moving infrastructure”, “hyper-speed systems” and other disruptive ideas. To achieve this objective, Transforming Europe’s Rail System defines a set of collaboration opportunities and hyperloop allocations using synergies and cooperation with the Knowledge and Innovation Communities (KIC) to increase demonstrations and facilitate deployment of technologies. Initial contacts have been established under the current S2R Programme and it will require further development. The work in terms of Energy KIC on Batteries can for example accelerate the hybridisation of rail traction systems; similarly, with the funding for hyperloop systems.

The European Railways Research Advisory Council, ERRAC, produced in December 2020 the document of Rail Strategic Research Innovation Agenda, SRIA (Shift2rail, 2020). This document converges to Transforming Europe’s Rail System but it provides the large spectrum for the sector to be usable in all activities of the Horizon Europe more than partnerships in the research of mobility 2030.

The Strategic Research and Innovation Agenda (SRIA) contains innovative operational and technological solutions demonstrated at pre-deployment stage (Innovation Pillar) where it is explicitly reported the new land guided systems for hyper speed, on demand services, flexible network. To understand what is expected from SRIA, transforming project number 8 defines the Non-traditional and Emerging Transport Models and Systems. Part A of the TP (Transforming projects) describes the understanding of innovation actions, expected TRL5 to TRL 8, (NASA, n.d.), finding the objective in Pilot operation for passenger and cargo markets, arising the need to develop technologies for switching the pods between different infrastructures. It is a clear conceptual aspect for the pilot covering the aspect where the demonstrator has the possibility of performing a complete operation but manually until the regulatory framework to get the certification to work under autonomous condition will be achieved. Part B of TP 8 contains the vision and challenges. In this section is explained that ERRAC gives the vision for hyper-speed systems as evolution of the current high-speed rail or maglev systems, but also possible new track-bound transport systems for public and freight transport to be interfaced and integrated with the current rail systems and other modes of transport.

This general framework gives opportunities to Hyperloop to find ways to receive funding from European Programmes, Horizon Europe as the biggest R&D action including the ERC actions, but also TEN of CEF activities when maturity allows to find the way. The actual challenge for the Hyperloop system is to mature adequately so as to become an option for the market and mobility. More specifically, the following progress is expected and should be aimed for:

- Safety conditions and operation is the integrity level requested for all mobility systems. Control and traffic management resources to operate in hyper high-speed condition demand depends on different technology approaches to research from the energy transfer to the pod, thermodynamic operation in the tube or safety distances between pods, including virtual coupling at high-speeds, are some examples of such aspects.
- Technology requested to preserve the operation in reliable and available terms is the first stage, permanent pumping to preserve the pressure of the tube is one of the challenges to advance the maturity level.
- Operational aspects like switching and crossing at stations to perform the movement at high speed is one of the bottlenecks to get a convergence from the hyper high-speed operation in the line to the station accesses.
- The integration of hyperloop in the urban landscape and its critical infrastructures requires a conceptual solution from collaborative actions covering social challenges and technological actions.

Mechanism to accelerate hyperloop has been launched:

- As a fact, in December 2020 the Hyperloop was included in the EU sustainable and mobility strategy. In FLAGSHIP 7 - INNOVATION, DATA AND AI FOR SMART MOBILITY (European Commission, 2020c) the Action 47 is referred to assess the need for regulatory actions to ensure safety and security of new entrants and new technologies, such as hyperloop. This is a critical action to get the appropriate framework to accelerate the actions to understand the Hyperloop in the board of transport possibilities.
- From the standardization aspects in February 2020 the Member States agrees to Establish Common Standards for Hyperloop Systems. For this purpose, it has been created the joint technical committee number 20, commonly named JTC 20 as part of the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization

(CENELEC). JTC will define, establish, and standardise the methodology and framework to regulate hyperloop travel systems and ensure interoperability and high safety standards throughout Europe, CEN/CENELEC (CEN/CENELEC, 2020).

8. Hyperloop Development and Infrastructure

The development of the hyperloop system triggers the exploration and understanding of integration between hyperloop in terms of intermodality, urban development, long distance development, integration and existing infrastructures. This section identifies the position of hyperloop concept in intermodal transport systems, urban development and long-distance development and establishes the requirements related to intermodality, urban development and rural development.

8.1. Stations

A key element of hyperloop infrastructure is a dedicated station. The development of hyperloop technology has been focused mainly on the transport vehicle itself and, in the background, on the infrastructure necessary for its movement along the route. The level of service that the hyperloop can achieve will mainly depend on the size and capacity of the pod, which can be set from 20 to 200 passengers and dispatching a vehicle every 18 seconds to every 2,5 minutes. This will require wide spaces focused on the embarkation of people and goods. In this sense, the impact that the hyperloop stations can generate in the surrounding area should be considered, not only because of the volume required for them but also because of the neighboring facilities that will allow the generation of new multimodal terminals.

These needs are also directly conditioned by the final location of the terminal for which it is currently recommended that it will be able to efficiently penetrate the centre of cities, either in their downtown or in areas where tourism has special interest. The final siting of hyperloop or intermodal stations is expected to act as a catalyst for population development as well as for the business network, so it will be necessary to consider it within the most ambitious urban expansion plans of cities. Simple hyperloop networks may approximate on-demand systems in their form of operation, although more complex networks will require a reservation system similar to that of airplanes or long-haul trains.

The following subsections explore and present the currently ongoing projects and concepts of the hyperloop stations, and outlines general guidelines regarding their functionalities.

8.1.1. Integration and design of the station

The idea of the hyperloop is to connect cities, which means that the hyperloop should start and terminate at urban centres. To increase the efficiency of the transport system, hyperloop stations should be integrated within an intermodal hub, alongside other modes of transport. Connecting the hyperloop with other already existing transport modes would allow for a seamless and effective flow of both passengers and cargo. Furthermore, hyperloop stations need to be designed with ease of travel in mind, ensuring wayfinding principles are maintained, which makes the navigation of the station simple, and enables an efficient flow of passengers.

As it was mentioned, designing a hyperloop station as a multimodal unit instead of a solitary station would have a huge impact on the transport sector. An example of such an integration, is to connect the hyperloop system to an airport, to allow for quick connection of remote regions to the airport, alongside enabling travellers to catch connecting flights from different airports. Cargo is often reloaded and transported via different modes of transport – a multimodal hub integrating a hyperloop system could potentially revolutionize the way cargo is being transported. Another vital aspect of the station's design are components of the station, which are responsible for the proper functioning of the hyperloop hub. Hyperloop stations need to be designed in such a way as to enable fast, efficient and automated transport of passengers. Some key areas of hyperloop stations to be considered during the design process are:

- Common areas for passengers
    - Customer help point
    - Staff seats
    - Local information/maps
    - Retail
    - Cash machines
    - Ticket machines
    - Gate-lines
    - Waiting areas
    - Security checking
    - Baggage tracking
    - Platforms
- Service points for passengers
    - Operational services
    - IT rooms
    - Integral equipment storage
    - Security offices and apparatus
    - First aid facilities
    - Cleaner's store and amenities
- Transport points
    - Pick-up & drop-off areas
    - Garage

8.1.2. Location of the station

Building hyperloop stations at city centres will directly contribute to urban development in a sustainable and energy-efficient way. By locating hyperloop hubs inside the city, cross-city routes could be created, enabling long-distance development. However, most big city central locations lack of free space place to construct a hyperloop station. A solution would be to place a new station in the suburbs, compromising the availability of space and the closeness to the city centre. Alternatively, an entirely different approach can be undertaken, with the placement of a hyperloop station in a rural rea. An advantage of this approach would be the available space for construction; however, it would lack proximity to more residential areas.

Another option (based on an upgrade of existing railway lines) is to utilize existing railway stations and expand them to accommodate the hyperloop system. The station itself would need substantial modernization to accommodate hyperloop operations (probably more frequent than conventional railways), yet it would be possible to use well-connected multimodal areas in city centres at a balanced cost.

8.1.3. Current progress on hyperloop stations

Several companies working on hyperloop, have revealed their plans and visualizations for the newly designed stations.

In 2016 Build Earth Live competition was held in Dubai, where participants were challenged to design hyperloop infrastructure (including vehicles for both passengers and cargo, tunnels, and stations) for a proposed line connecting Dubai and Fujairah (Blackburn-Dwyer, 2016). Participants had only 48 hours to develop their ideas, which were then presented before the jury. Each design had to lay plans for parallel hyperloop transport systems – one for passengers, and one for cargo – that would eventually converge into one station at the finish line. Projects had to include complete stations with spacious halls for passengers to board on the trains. The competition attracted international media attention, with teams from all over the world taking part. The seven finalists of the competition included rLoop, BIM Unlimited, BIM Fusion, Nevomo (then Hyper Poland), Mobius (Figure 20), Systra and Hypernova.

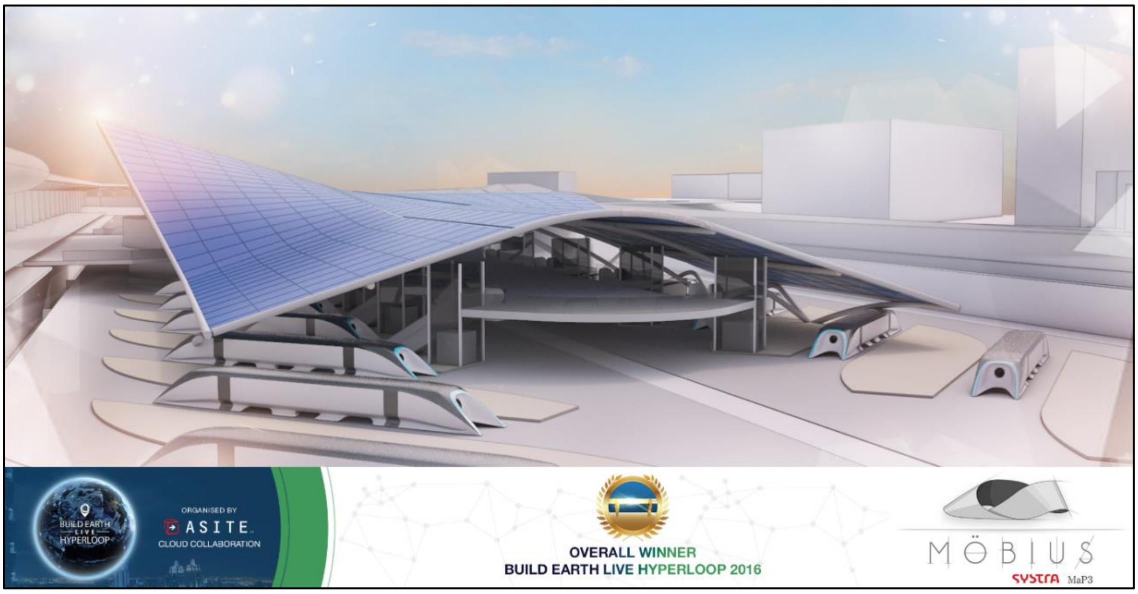


Figure 20. Visualization of Mobius - the winner of Build Earth Live Hyperloop 2016, image courtesy of Build Earth Live (Murphy, 2021)

One of the participants of Build Earth Live was Nevomo, who took part in the competition in collaboration with Wheeler Kearns Architects and iTech Management Consultancy (Nevomo, 2016). The team earned the BIM for Innovation award at the competition (Kearns, 2016). Nevomo and Wheeler Kearns Architects combined their ideas and expertise to create a shared vision for the competition, which included rearranging the turntable and repair area relative to the passenger lobbies which then reduced the core of the building length by over 100 feet. Further modifications reduced it closer to the ideal footprint of 300'x300', which approximates half a city block. The principal goal in the competition was to show how technology could allow ultra-fast transport within different dense urban contexts. To facilitate this, the team suggested a core and enclosure approach; the same optimal core is used at all stations and a flexible enclosure modifies its shape and material to cater to a new context (Figure 21). Additionally, the design of a midway station was explored, which utilized Nevomo's adaptable gantry system (Figure 22).

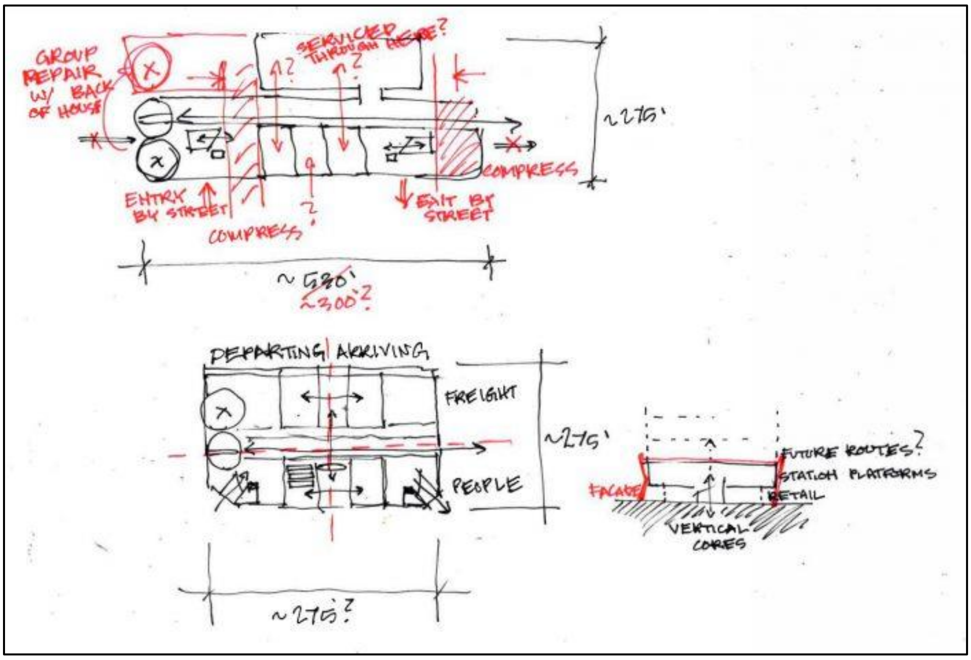


Figure 21. Sketches of the project for the Build Earth Live competition by Nevomo and Wheeler Kearns – image courtesy of Wheeler Kearns Architects (Kearns, 2016)

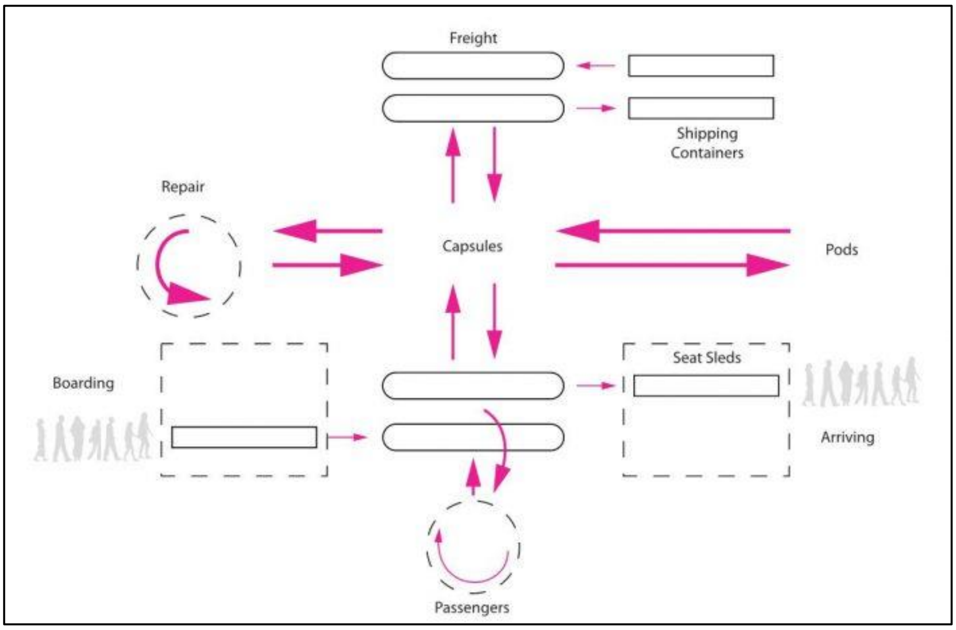


Figure 22. Scheme of the designed hyperloop station for the Build Earth Live competition – image courtesy of Wheeler Kearns Architects (Kearns, 2016)

Nevomo and Wheeler Kearns also worked on designing three separate hyperloop stations on the route between Dubai and Fujairah. Each station needed to serve both freight and passenger tubes, nearly doubling the necessary infrastructure. One challenge of the competition was that the station sites, which included Fujairah Airport and Dubai International Airport, were located further from sites in dense areas that obviate a second leg of travel. By necessity, the airports stood in outlying areas, negating the advantage of connecting two urban cores at the hip. However, since the Dubai international airport is relatively close to its urban centre thanks to the recent construction boom, metro lines converge close to the airport (Figure 23 and Figure 24).

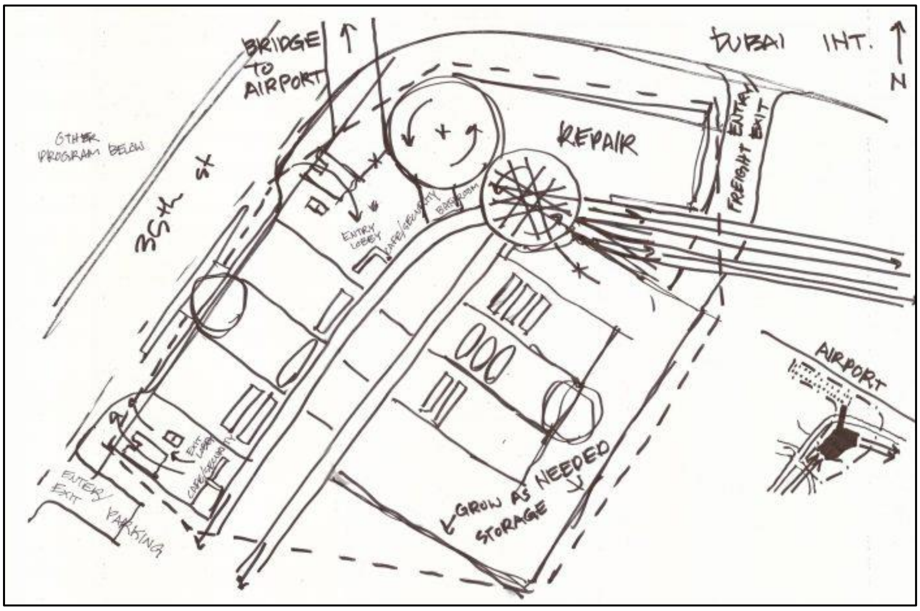


Figure 23. Hyperloop station in Dubai, designed by Nevomo and Wheel Kearns – image courtesy of Wheel Kearns Architects (Kearns, 2016)

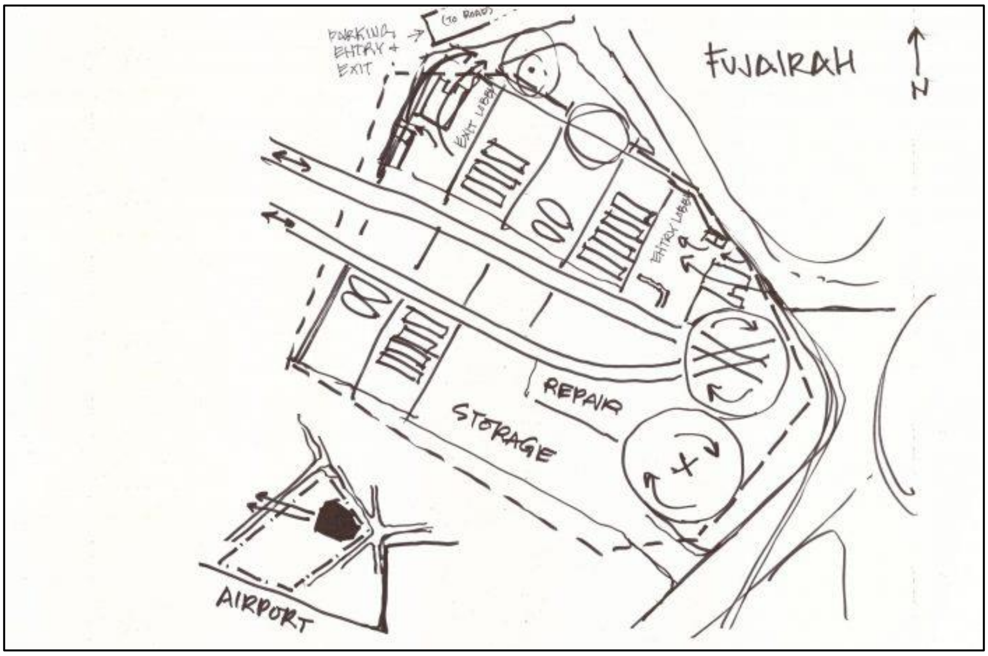


Figure 24. Hyperloop station in Fujairah, designed by Nevomo and Wheel Kearns – image courtesy of Wheel Kearns Architects (Kearns, 2016)

Nevomo and Wheel Kearns Architects also collaborated in 2017 for the Specialized Expo 2022/23 which took place in Paris (Foljanty, 2017). During the event, the two companies have jointly designed a hyperloop station, specifically for the city of Lodz, which was the candidate for Expo 2022. The team jointly designed the exhibition pavilion dedicated to Hyperloop technology where the guests could have found the unique simulator built into the portion of the station in a 1:1 scale and experienced the system in virtual reality (VR). The pavilion was designed so that after the Expo 2022 it would have been possible to convert it to a fully operating hyperloop station, creating a convenient transport hub in the city centre. The central location of the station was a crucial aspect in the design process, as the functions necessary to redirect pods and offer comfortable, safe, and efficient departures and arrivals were all designed to minimize the footprint of the building, allowing the stations in the system to fit in dense central business districts and connect cities together. The design allows either above or below ground tubes depending on local conditions without changing the organization of the boarding platforms, clarifying wayfinding through daylit spaces while also responding to the built context of Lodz through material choices.

In 2017 TransPod published a visualization of Toronto's intermodal station (Transpod, 2017a), which includes the following means of transport: hyperloop, regional trains, subway, streetcar, and buses (Figure 25). The intermodal hub is spacious, equipped with double security and boarding checks, as well as a food court and leisure spots for the passengers (Figure 26).

Figure 25. Overview of hyperloop station by TransPod – image courtesy of TransPod (Transpod, 2017a)

Figure 26. Hyperloop vehicle arriving at the station – image courtesy of TransPod (Transpod, 2017a)

In 2018, UNStudio, a Dutch architectural practice, designed Hyperloop Hub for Hardt Hyperloop (UNStudio, 2018). The project imagined a hyperloop station as a multimodal hub, with components allowing it to be adapted to a range of contexts: city-centre, city periphery, or joint to an existing infrastructural hub, such as an airport. The station was designed in flexible modules, to accommodate the wide range of potential uses (Figure 27). Each module can be reconfigured and adapted as needed, to hold different functions, such as luggage check-in, parcel pick-up points as well as leisure areas for children and adults (Figure 28).

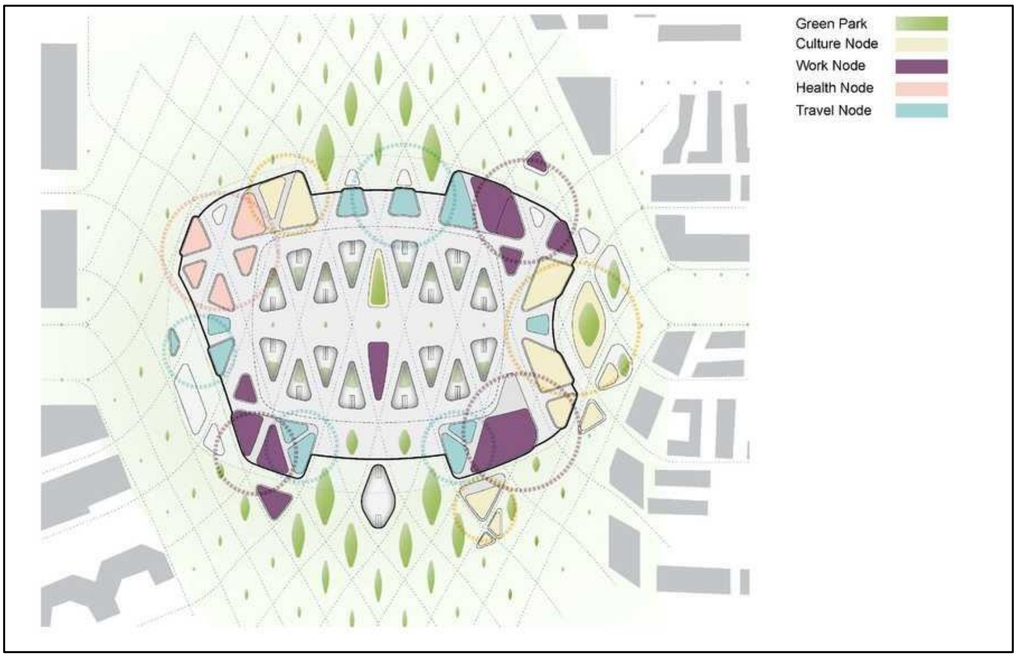


Figure 27. Station concept – an extension of the urban fabric – image courtesy of UNStudio (UNStudio, 2018)

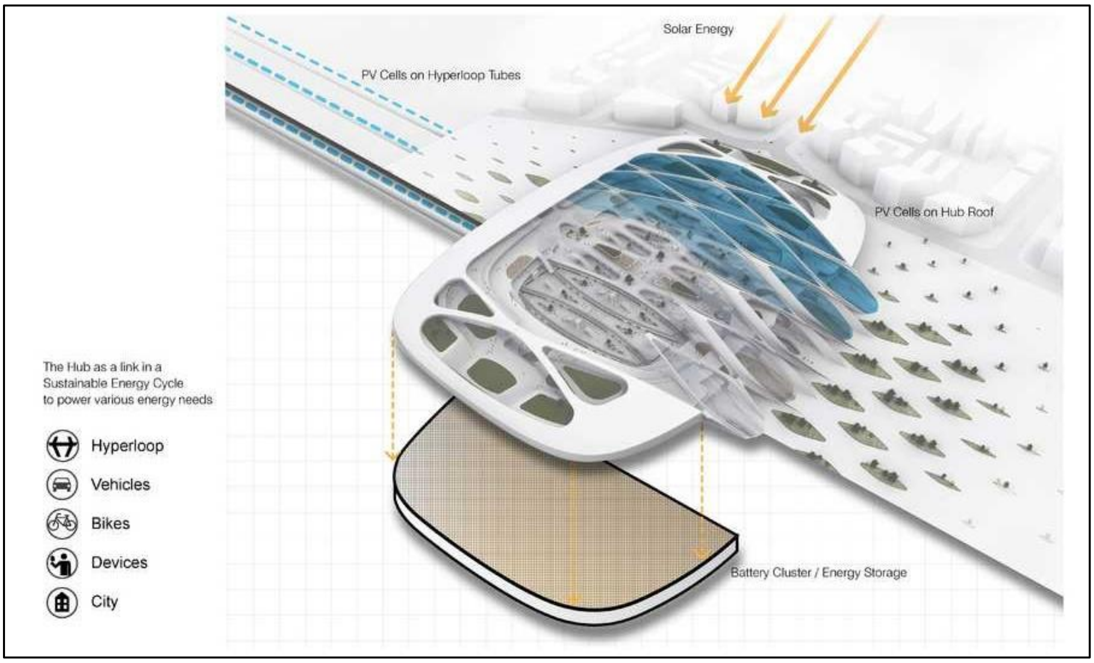


Figure 28. Station concept – Energy storage – image courtesy of UNStudio (UNStudio, 2018)

In January 2021 Virgin Hyperloop shared its passenger experience vision following the company's first passenger vision (Giacobbe, 2021; Virgin Hyperloop, 2021a) (Figure 29). Virgin Hyperloop's rendition of a hyperloop station is also of an open and spacious centre, with floor-to-ceiling windows and minimalistic interior design. Virgin Hyperloop's platform is showcased as easy to navigate, to enable effortless boarding and disembarking of passengers (Figure 30, Figure 31).

Figure 29. The exterior of the Virgin Hyperloop station in Mumbai – image courtesy of Virgin Hyperloop (Giacobbe, 2021)

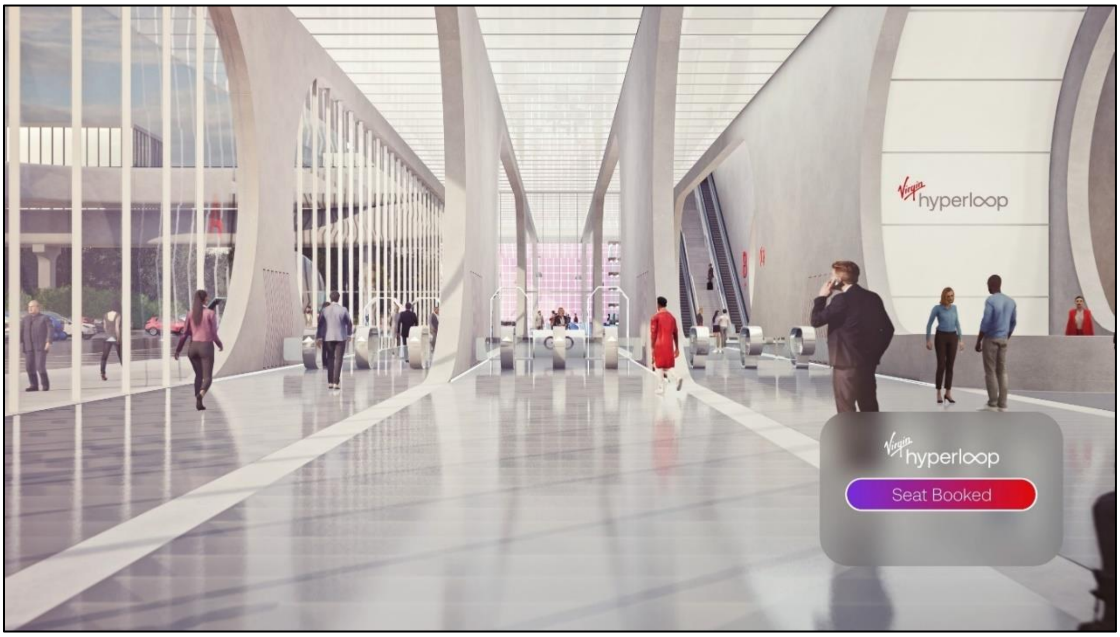


Figure 30. Interiors of the station - images courtesy of Virgin Hyperloop (Giacobbe, 2021)

Figure 31. Platform of Virgin Hyperloop's station - images courtesy of Virgin Hyperloop (Giacobbe, 2021)

In comparison with the other designs, Zeleros shared its designs of stations, highlighting the benefits of the simpler boarding procedures, which are similar to high-speed rail or metro. Passengers would board the vehicles and then enter the tube, where the depressurization process starts. That way, passengers don't need to enter through an airlock. Zeleros' stations can be integrated with the urban landscape in multimodal hubs, where metros, high-speed rail, bus, bike or ridesharing apps can be taken, maximizing passenger experience (Zeleros, 2021a).

Figure 32. Overview of hyperloop station boarding gates by Zeleros – image courtesy of Zeleros (Zeleros, 2021a)

Figure 33. Overview of hyperloop station interiors by Zeleros – image courtesy of Zeleros (Zeleros, 2021a)

Figure 34. Overview of hyperloop exteriors by Zeleros – image courtesy of Zeleros (Zeleros, 2021a)

8.2. Urban development

The impact of hyperloop on the environment is still unknown. This is mainly because it is a new disruptive technology. Most proposed hyperloop networks connect major cities. This could lead to an increase in urbanization, since citizens are expected to concentrate around central nodes. Unlike airports, which are mostly located in the suburbs, hyperloop stations can be located also in the city centre. This will reduce the point-to-point travel time and will make the catchment area of hyperloop stations larger.

Tubes for hyperloop will be constructed both over-and underground. For over ground cases, noise pollution must be considered. It is expected that the pressure in front of a capsule will generate the tube to swing. The noise emitted is predicted to be smaller compared to other transport modes. Elevated tubes in urban areas are also a major societal issue. The lack of space, potential opposition by landowners and legal issues may cause difficulties and increase cost and construction time.

Shorter travel time between mayor cities will open up job opportunities and have a positive impact on tourism. A shorter travel could also solve the housing crises and reduce cost of living since people will be more willing to live in a different city than the one in which they work in. Hyperloop stations are expected to have good intermodular transport connection and reduce the environmental impact and make cities cleaner and safer.

In the Roadmap to a Single European Transport Area, the European Commission plans towards a better connected, competitive and resource efficient transport system. Part of this is the goal to finish a European highspeed rail network by 2050. This includes connecting all airports to the network, primarily to the highspeed network. Tube transport is not mentioned in most urban development strategies since it is a new innovative concept and more focused on medium to long distance travel and not for commuting in a city. For the most part, the requirements can therefore be derived for high-speed trains.

8.3. Long-distance development

Hyperloop is a novel means of transport and its main feature relies on its intrinsic ability to reach ultra-high speeds with a very low energy consumption. In this sense, this capacity confers this technology the potential to connect short routes efficiently and, especially long terrestrial routes. To ensure the future deployment of hyperloop, both technology and regulation must be in place. Additionally, market acceptance from clients and users is a must, and a crucial contribution is provided by its capacity to fulfil a sound business case that facilitates a modal shift from alternatives means and expand the current demands served by incumbent technologies.

During the last century, those challenges have been overcome by the two most relevant mass transport technologies operating in long-distance routes: planes and trains. Therefore, relevant insights can be extracted from the analysis of those steps covered during the last century. It was in 1914 when the first commercial aviation flight was registered in the USA. (Figure 35).

Figure 35. First commercial flight in the US (PBase, n.d.) **(left). B314 Clipper, a transatlantic hydroplane** (Wikipedia, 2021b) **(right).**

Hydroplanes, as the purest form of aviation given their near-zero infrastructure dependency, evolved into a much complex machine, able to cross the oceans. Tickets were not cheap, but those who could afford it avoided crossing the Atlantic by boat, a much slower solution.

Two extreme developments, increasing capacity and speed, were developed: A 380, with a capacity of up to 850 passengers (left). Concorde, with a speed of 2,200 km/h. none of them succeed due to several and complex reasons that should be analysed to accommodate the understanding of the future market penetration scenarios for hyperloop. The Concorde's energy consumption made it affordable to a sufficient, but limited, number of costumers. In the case of the A-380, it was the hub and spoke model what failed, since customer (operators) preferred the point-to-point model. Despite technological improvements, when business models fail, solutions are usually disregarded. The business model first input is raw demand volume, followed by customer acceptance. In brief, insufficient demand from customers (operators) for the case of the A380, and lack of user acceptance (passengers) in the case of the Concorde, were the drivers behind their failure. Apart from the failed propositions, the aviation industry clearly holds a series of unique benefits, such as:

- The ability for flexible operation (operate on different routes)
- The ability to overcome water or heavily mountainous areas
- The opportunity to provide service between far away isolated communities within the same piece of land. A paradigmatic instance could be Moscow and Vladivostok, but also Denver and Seattle.
- Its cruise speed: unmatched on the cruise phase of the trip. - Its cruise speed: unmatched on the cruise phase of the trip. However, to account for passenger movement (to and within the airport) or luggage collection (if any), the focus should be put into the average speed. In this case, beyond 2,000km, non-stop flights currently have no match in terms of average speed, being the fastest solution available. Interestingly, in Europe more than 90% of passengers flew flights of less than 2,000 km (source).

Figure 36. Transrapid (maglev) train in Germany (Wikipedia, 2020) **(left). Chuo Shinkansen (SCMaglev)** (Railway Gazette, 2020) **(right).**

Aviation is not the only technology that can match the needs for passenger and cargo transport for long distances. From its invention in early 19th century, railway has evolved deeply specially regarding speeds. Today, terrestrial guided transport means can levitate and move at speeds beyond 450kmph (Refer to Figure 33).

Other technological enthusiasts foresaw that there was an opportunity ahead for strengthening land-based solutions and producing maglevs. Maglev implies that the standard wheel to rail contact is replaced by a contactless magnetic cushion.

This calls for a high-capacity solution that can absorb a high demand market that, subsequently, grants high levels of revenues by itself, or greater benefits when network effects are considered. In this sense maglev, same as trains in general, perform very well. They just need to be placed at the correct location. However, and putting aside some aspects like preferences for oil economy, less pressure from the sustainability perspective, the solution was:

- Not interoperable with conventional rail.
- Noisy at ground level from 450 km/h onwards (EC, 2003).
- Unable to match the speeds of aviation, except for a very specific niche: only in less than 500 km routes they can be a true aviation challenger.

With this mix, the analysis found several reasons for their fate, but just a few are pointed out. In this sense, the German maglev failed after reaching operational maturity, given that its speed was not over the 450 km/h (testing 500 km/h), therefore insufficient to remove the HSR lock-in and growth projections, and the construction cost, when translated to 2021 prices, was around 50 M€/km (Heller, 2008; ThyssenKrupp, 2008), while HSR construction cost floated around 15 M€ in continental Europe. In the case of the Japanese one, still not in commercial service but already certified for operation, seems to have found only a market niche on its own country on a single route. For this type of maglev, the price per kilometre exceeds the 150 M€/km, and even 200 M€/km (Sato, 2014), ten times more than an HSR.

Aside from the cost itself, it gets the label of a luxury product, hard to market even when long term economies seem to pay off at the end of the lifecycle. To sum up, maglevs seem to have been discarded not because of its performance, but because they were too different without any key advantage against other solutions; the fast and polluting mid-size twin engine aircraft, and the comfortable but sooner or later limited HSR (UIC, 2018), even after some pending evolutions.

When the focus is placed on how markets introduced air and rail long-distance and high-speed solutions, every region opted among the different solution alternatives using a logic based on its own preferences and resources, which are also dependent upon time. As a result, and only for the passenger case:

- USA has focused on aviation for passengers, independently from trip length.
- Europe has a mix of aviation and rail for passengers, depending on trip length.
- China has focused on Rail for passenger, independently from trip length.

A key question is in which conditions an air passenger will prefer to use a land solution, generating a high amount of discussion regarding the modal shift in the literature. Strong local conditions apply. For example, the policies from France and China foster the usage of the HSR. The exception in France is Paris-Toulouse, being Toulouse the main aeronautical pole in Europe. The literature for Spain (Castillo-Manzano et al., 2015), for instance, indicates that modal shift for the Madrid-Barcelona expectation was to reach around 91%. However, and despite the enormous success and the high occupancy of the Madrid-Barcelona (>90%) and the high modal shift, the forecasted levels have not been reached yet, 13 years after inauguration. In other words, HSR and the airlines seem to offer more independent services than at first might appear. On the other hand, a study carried over the main 3 country legacy airlines indicates that they have suffered a strong negative impact on their demand after the introduction of parallel HSR service, coupled with an elasticity increase in the air passenger demand.

Also, the modal shift seems to be more prominent in lines with lower levels of demand, compared to those with high demand levels. To avoid price wars with airlines, HSR lines should be introduced in high demand routes, given that when HSR entered low demand lines, airlines reduced their frequency or even stop their service (Zhang et al., 2017). Another study shows that the HSR effect varies across different routes, travel distances and city types. The impacts are found, however, much stronger among those air routes that connect major hubs within a distance range of 500 to 800 km, but always outlaying an uneven nature of the HSR impact (Chen, 2017).

As exposed, different analysts have different conclusions, but one trend emerges: if there is an HSR service and the ticket price is in similar range and considering that most HSR city pairs are within distances of 750 kilometres, given the chance to select, the majority of passengers will choose the land transport, and if there is a train, they will take the train (Figure 37).

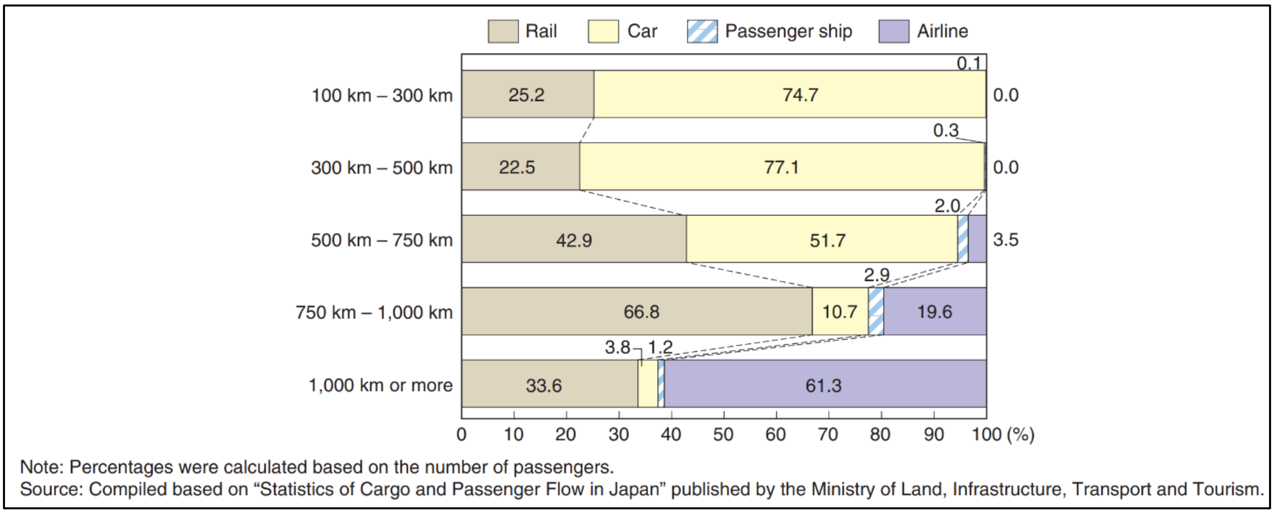


Figure 37. Airline and rail supporting medium and long-distance transport in Japan in 2007

(Sano & Kotaro, 2015)

Three main aspects are considered to drive railway transport:

- Comfort: which includes not only the convenience inside and outside the vehicle but health related topic, safety perception, perceived security, noise disturbances.
- Reliability: On time performance, predictability, weather dependency.
- Sustainability: It contains factors such as direct GHG emissions, energy consumption and source of the energy, visual impact, integration with nature or the branch of noise that involves pollution.

If these decision-making aspects are added to the usual speed and capacity vectors, a fair board of vectors arise to properly compare transportation alternatives nowadays (Figure 38).

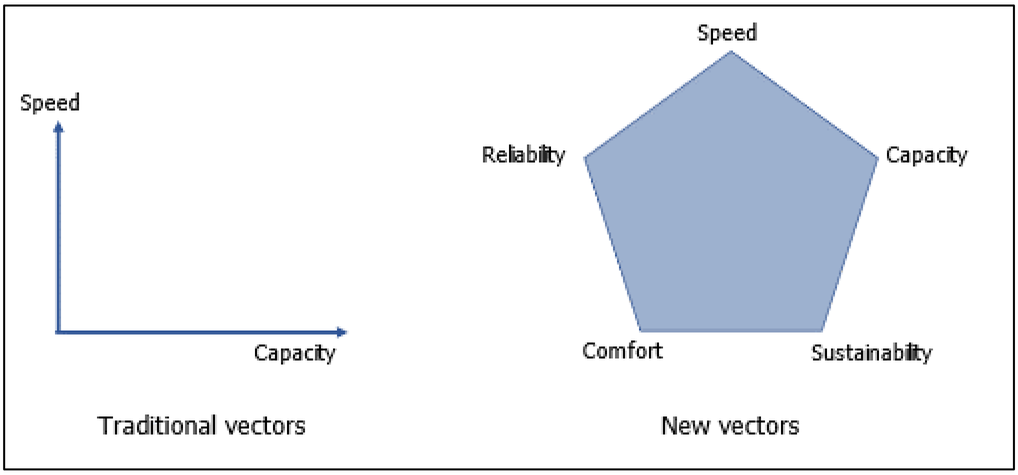


Figure 38. Vectors to benchmark current transport solutions

As will be described in the following pages, the features of hyperloop will allow to challenge the aviation monopoly in certain distance segments, allowing for the modal shift to happen. It will be demonstrated that, within these segments, hyperloop can be the potential solution of choice for users because of comfort and reliability, and because of sustainability backed primarily by customers (operators), that will be pushed by regulators and users. Environmental regulation will play a fundamental role. Some movements in this direction could be observed, for instance, in the Air France-KLM Group, representing a major operator.

In 2020, KLM decided to start operating trains that replace what otherwise will be short haul routes (Nikel, 2019). In 2020, The French Government bailed out Air France during the COVID crisis (Alderman, 2020). The exchange offers concerned Air France stopping short haul flights when an equivalent rail solution in terms of travelling time was available. France model is of particular interest because it combines a long and fast High Speed Rail service and an Energy policy that uses electricity not coming from fossil fuels, that allows, under a regulation mandate, to eliminate flights when a true alternative for the users exist. It is also interesting to observe in this instance the public-private equilibrium towards a transportation model that follows social demands (with a focus on comfort, sustainability, and reliability), coming, nonetheless, from citizens.

8.3.1. Introduction of the hyperloop

During the last century, medium and long-distance fast transport has been accommodated mainly by railway and aviation. These mobility technologies have helped shaping regions, trade, and tourism, generating value, wealth, and economic growth for society. When speed is the key driver, air connections between cities have traditionally absorbed most of these traffics for more than half a century, mainly due to a unique ability to link far away locations by a sufficiently convenient manner. Aviation, through its speed, grants a shorter journey time, with an imposed level of comfort that must be accepted because of the lack of true alternatives. Hence, airport queuing, cabin shakes or hard landings, among others, are tolerated (Figure 39). Technology certainly helps on damping these uncomfortable situations, but most of the airplane ride features are bonded to its airborne nature and cannot be changed.

It is only on those routes where a land transport solution is not possible, such as the connection between islands, or where orography dictates extremely high construction costs, or where distance exceeds regional range, where flying will be usually, preferred. As a framework to compare, the door-to-door concept helps to understand burdens of different technologies. In Figure 39 it is possible to observe how aviation suffer limitations as the airport is by nature located out of the city and, the process to access the vehicle is also much more intense and time consuming in general, due to security and logistic reasons.

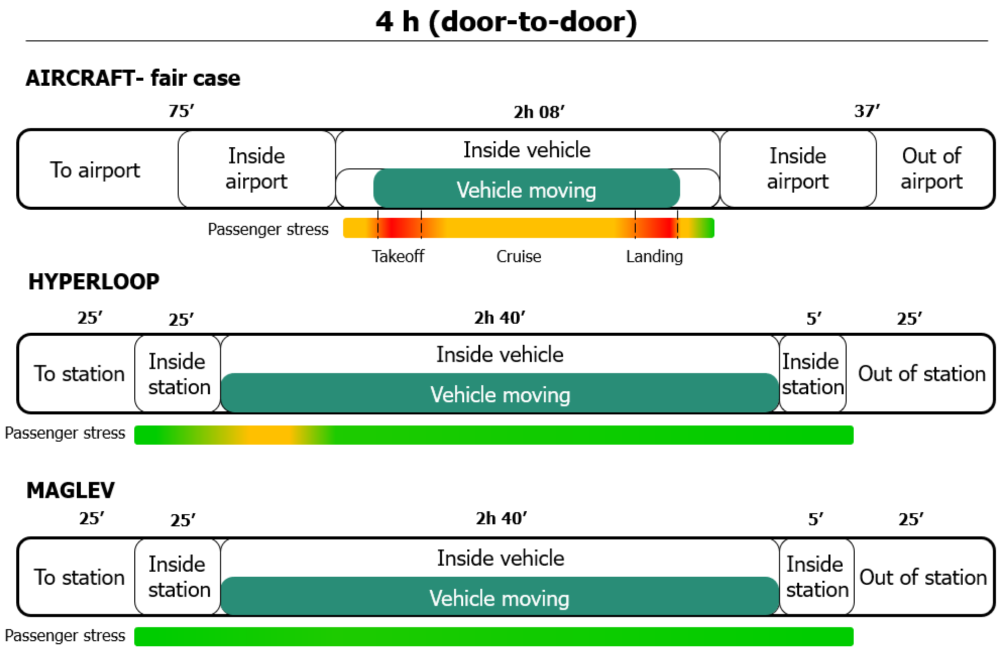


Figure 39. Journey times breakdown: aircraft, hyperloop and maglev

The hyperloop greatly opens the possibility of extending the range of routes where comfort and environmental friendliness can be paramount. Compared to the 4 hours of the HSR, the hyperloop will stay at 100 minutes on a 1,000 km route. This implies the possibility of adding a dramatic improvement in terms of speed (Figure 40).

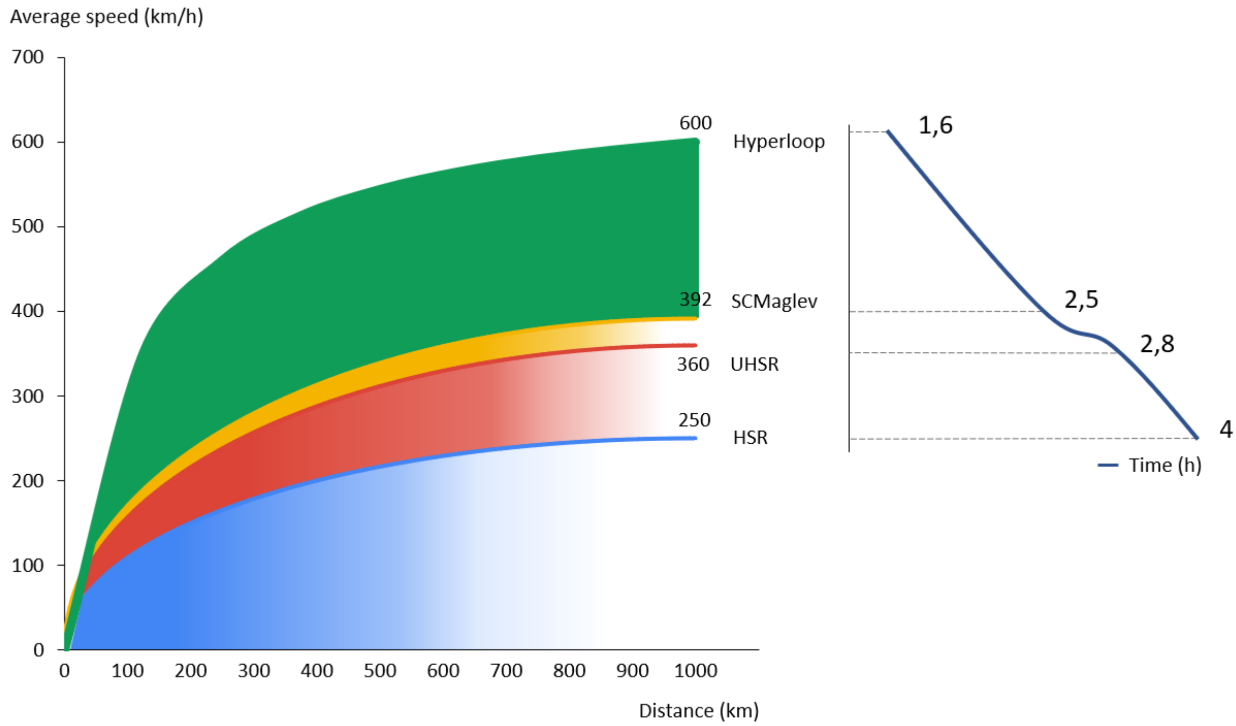


Figure 40. Average speeds and travel times for a 1,000 km route

The emergence of new ultra-high-speed transport systems delivers a clear increase on the average speed with respect to the dominant land solution, the HSR. However, these alternatives, to be competitive, must maintain an infrastructure cost range that allows the techno-economic viability of the project. In the case of the HSR, the potential evolution to Ultra-High-Speed Rail UHSR implies a potential increase in the cost of the infrastructure due to the need for better properties (alignment, power transfer, wearing parts, noise abatement), what increases the maintenance costs as well. Thus, in several cases the HSR remains at 250 km/h, as top speed.

The average cost of HSR is 36 M€/km (Armitt & Houghton, 2016) and has been maintained for the UHSR despite the added requirements (**Error! Reference source not found.**). The chart also showcases how all different maglev solutions have higher infrastructure cost than HSR, a key factor for their lack of market penetration, together with their marginal speed advantage compared to a potential HSR evolution. On the other hand, the hyperloop shows different cost depending on the pressure of operation and propulsion system. Thus, for a similar speed benefit, Zeleros proposal, with most active key technologies onboard (propulsion, energy storage, levitation) and a much simpler infrastructure that works with aviation pressure levels mimics HSR costs, thus making it more suitable for long distances. This is why this solution might be especially suitable for long distance hyperloop routes, where the business case would be negatively impacted by growing Capital expenditures.

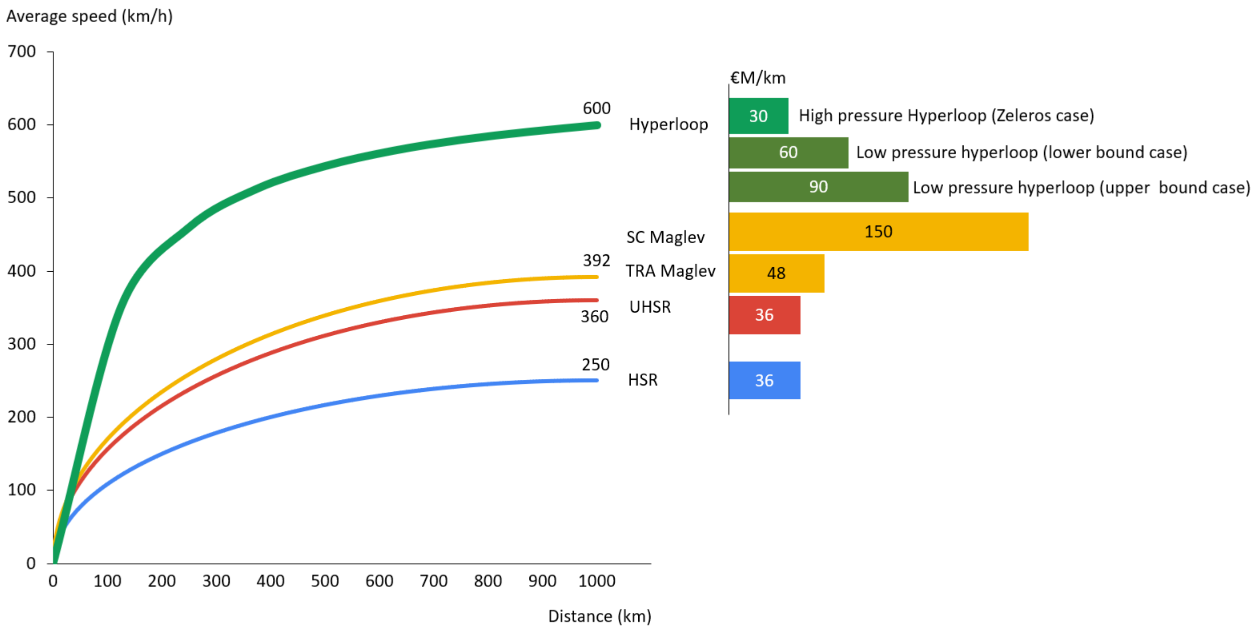


Figure 41. Infrastructure cost of land transport

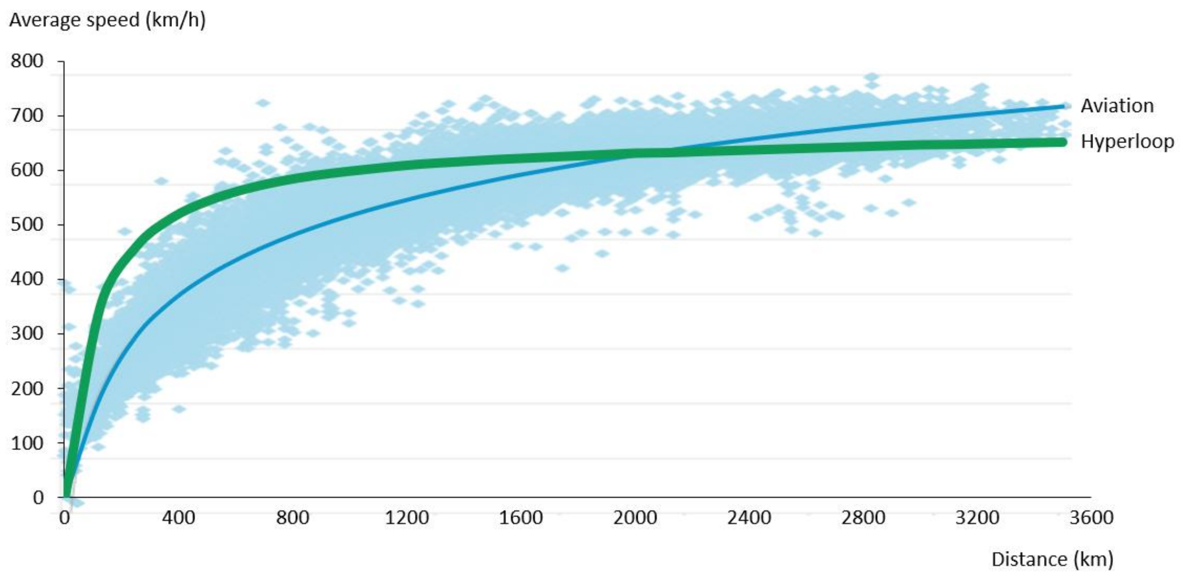


Figure 42. Hyperloop and aviation speed profiles

The generic approach to the hyperloop technology considers a vehicle that magnetically levitates and moves inside a tube at low pressure. Two strategies arise to avoid the piston effect. One approach consists of an extremely low-pressure solution, close to space conditions. These concepts are based on maglev systems, with a linear motor as a propulsive device, deployed along the track, and in development by Virgin Hyperloop One (USA), HTT (USA), Hardt (NL) and Nevomo (PL). Maglev-based approaches encounter the same limitations as maglevs, such as the high cost of infrastructure, that adds up to a low-pressure vacuum system in addition to a tubular enclosure. The second approach incorporates a turbo compressor. This rotary machine is included on Zeleros (ES) and Transpod (CA) concepts, and the main disadvantage is the increased complexity and cost of the vehicle itself. Transpod relies upon linear motors for the propulsion, while Zeleros, the only approach operating at higher pressures (aviation-like), uses the turbomachine to generate thrust, too. By embedding the propulsion in the vehicle, Zeleros manages to simplify the infrastructure, resulting on an average cost of 30 M€/km, close to the 36 M€/km of HSR, while the technology enables more than twice the average speed.

Aviation dominates the transport of passengers and high-value goods in medium and long-distance routes, thanks to its speed, versatility, and wide range of routes and connections at a national and international level. A key challenge for hyperloop is to prove its speed considering the top speed of commercial aviation, that lies within the 850 to 950 km/h range. For the region of Europe, the German Space Agency (DLR) has analysed the average speed of all flights of a year, on a gate-to-gate basis, for all route distances (Figure 42).

It is possible to identify the calculated mean speed value for aviation (Figure 39). The blue cloud depicts that, for different services of the same length, there is little repeatability due to route characteristics conditioning the operator's decision. These conditions are traffic, the use of different aircraft, seasonal change in winds, or seasonal delays. Conversely, on the hyperloop case, the variability of "weather" environment and route length is always reduced to a close-to-zero value.

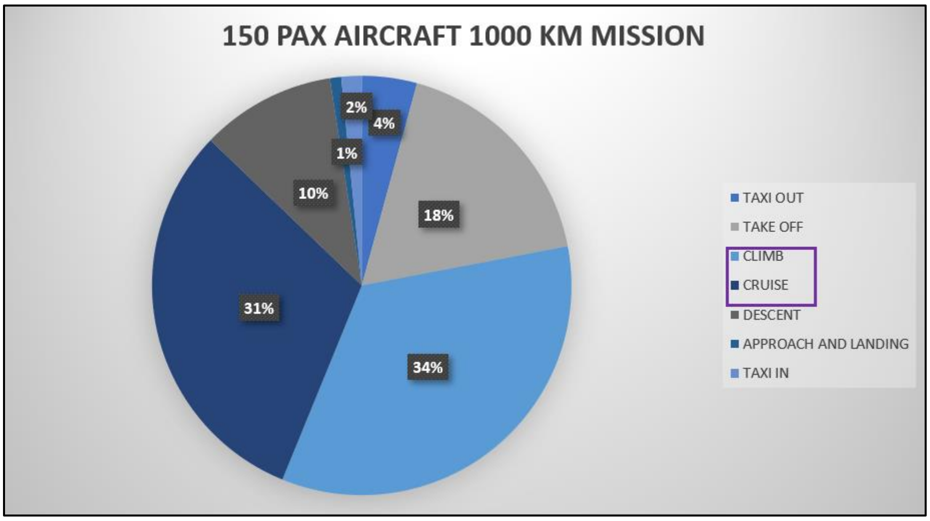


Figure 43. Time spent on each flight phase for a 1,000 km route.

In terms of speed, aviation is heavily penalised in shorter routes, because of the taxi and climb phase (Flightaware, 2021) (Figure 43**Error! Reference source not found.**). All the flight phases not being cruise (where fastest speed is achieved), lower the average speed of the solution. Not only taxi and climb, but after cruise, the descent phase happens, lowering, again, average speed.

The hyperloop, while respecting comfort, manages to reach cruise speed faster, thus maximizing cruise speed time. This is achieved by the technology itself and a proper alignment, where the vehicle can maintain its cruise speed during most of its journey (85% compared to less than 50% of the airplane for a 1,000km routes). Systematically, it outperforms aviation on routes of up to 1,200km, and remains competitive beyond 2,000km, the latter representing 90% of all flights in Europe (Grimme & Maertens, 2020). Beyond that threshold, aircrafts can operate longer times in cruise improving their average speed and hence, obtaining the best value of time of any transport solution.

Finally, being a 100% electric transport with zero direct emissions (Figure 44), hyperloop can enable the decarbonisation of operations in those aviation routes where emissions per passenger/kilometre are more penalized: short to medium distance routes, where aviation efficiency levels are at its lowest (ICCT, 2020). These facts, added to the fact that hyperloop can be brought to city centres given its reduced needed space and low acoustic impact, adds key elements for users to promote a modal shift from the regional aircraft on those routes of less than 1,500km.

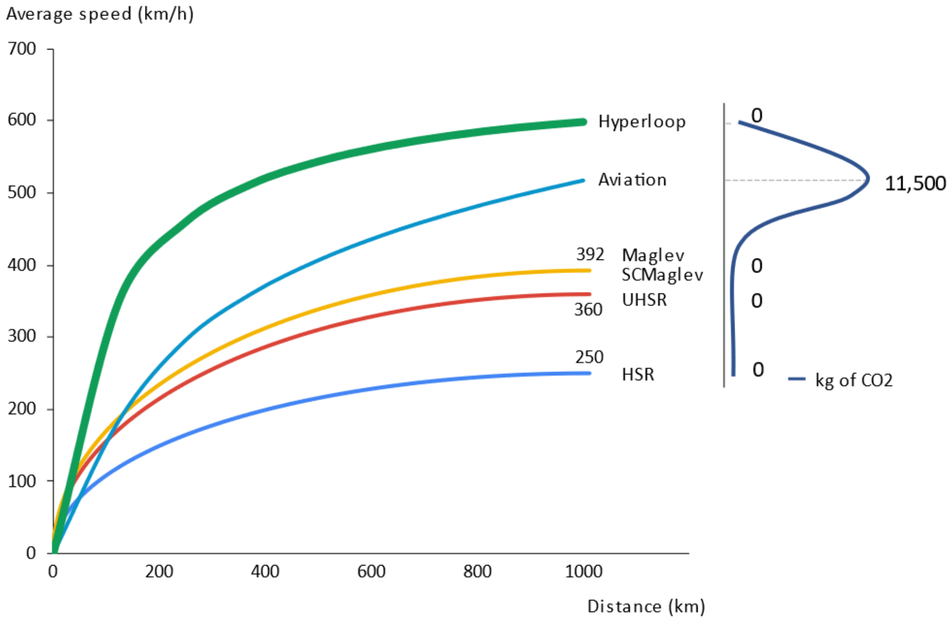


Figure 44. Emissions of current transport solutions for a 1,000 km route

Thus, the hyperloop has the potential to expand the rail mobility limits for users towards a higher standard of value of time, while maintaining or even improving comfort, and allowing for clean transport with acceptable infrastructure costs. Thus, when the construction costs are offset by the benefits the hyperloop provides, the hyperloop can replace aviation, delivering a better environmental performance and comfort.

Therefore, the advantage of taking on a technology leap is justified because, (1) HSR evolutions will find sooner or later a technological limit (UIC, 2018), being significantly distanced from the capabilities of hyperloop, (2) maglevs already impose a non-interoperable solution with HSR, coupled with its lower performance, and potential growth, against hyperloop (Figure 45). Against aviation, the construction costs are offset by the benefits that hyperloop provides when replacing certain aviation routes. Hyperloop can deliver a better environmental performance and comfort, and since aviation routes are long, it can provide an opportunity for fast connections of medium-sized cities to the larger ones (beyond 1,000 km), historically connected only by airlines.

Q.4 Is it possible to increase the maximum speed in the future?

A. Since the Superconducting Maglev runs while being levitated with magnetic force (contactless), it is logically possible to have a higher maximum speed. However, a higher operation speed would make the train subject to greater air resistance. This would require power equipment that can withstand such resistance, and is therefore impractical.

Figure 45. Super conducting maglev developers' answer regarding a potential increase on speed

Since comfort in maglevs exceeds that of HSR (or UHSR) and the fact that SC Maglev consider impractical rising their speed in open air conditions, while being intended to operate at top speeds of 500km/h, then, from the perspective of a new technology land transportation solution, there is an opportunity for one that provides a similar comfort level, at higher speeds, but maintaining construction costs at a reasonable level to withstand its deployment with a business case. It is acceptable to state that hyperloop's comfort levels will be at those of maglevs because of its technology (magnetic levitation as suspension) and driven by the same human factors in the making.

Still, maglev is a clearly a state-of-the-art high end quality product, ready for commercialization. A basic comparison is presented in Table 5.

Table 5. Comparison among maglev and hyperloop

PROS	
MAGLEV	**HYPERLOOP**
Off the shelfs solution	Some hyperloop technical solutions enable a cheaper infrastructure cost than maglevs
Able to start and stop	Fast enough to beat airplanes: more market
Grades up to 10% (source)(Transrapid case only, 4% for SC Maglev (source))	Lower energy consumption for the same speed
High capacity (1,000 pax on SC Maglev only)	Medium capacity: - Enough for long distances - Concept upgrades target high capacity
CONS	
MAGLEV	**HYPERLOOP**
Not fast enough to beat airplanes	On R&D phase
Outrageous infrastructure CAPEX	Handling vacuum of infrastructure

The key takeaway is that maglev has little to offer compared to a UHSR, and given the immense deployment of HSR, maglev should have provided additional benefits compared to the HSR to justify the investment. Conversely, some incremental improvements can still be applied to HSR, but in this case there is a clear cap.

These combined benefits offered by hyperloop can be depicted in Figure 46, by analyzing a door-to-door journey. Aviation, by having the lower time with the vehicle moving (Grimme & Maertens, 2020), becomes penalised in terms of average speed. On the other hand, hyperloop and maglev solutions span for longer times because of the fact that stations are generally in city centres and not much time is spent inside them, contrary to airports. On the comfort side, the passenger is generally more stressed during an aviation journey than during a maglev/UHSR one (take-off and landing, safety procedures, seatbelt, etc generate passenger stress). In terms of distance travelled, it is depicted that below the 3-hour door-to-door journey (1,500 km range), hyperloop is the solution traveling longer distances against maglev or aircraft, thus providing a higher value of time through its speed capabilities.

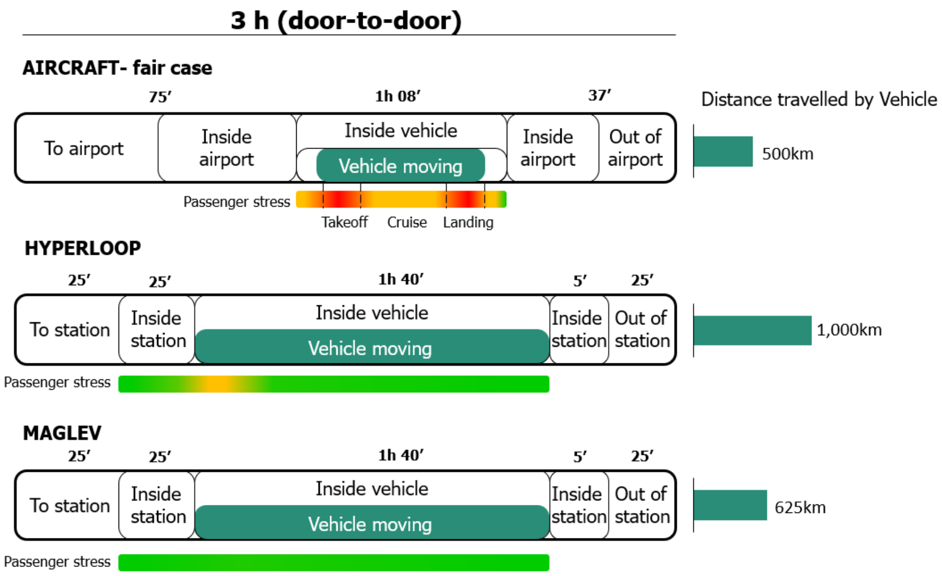


Figure 46. Door-to-door journey breakdown

The following subsection will explore the different future scenarios that could appear depending on the answers given by deciders to the very same questions.

8.3.2. Hyperloop within the portfolio of transport solutions

Nowadays, the mobility solutions domains for high speed and long distance on commercial basis are currently split between aviation and high-speed rail (Figure 47).

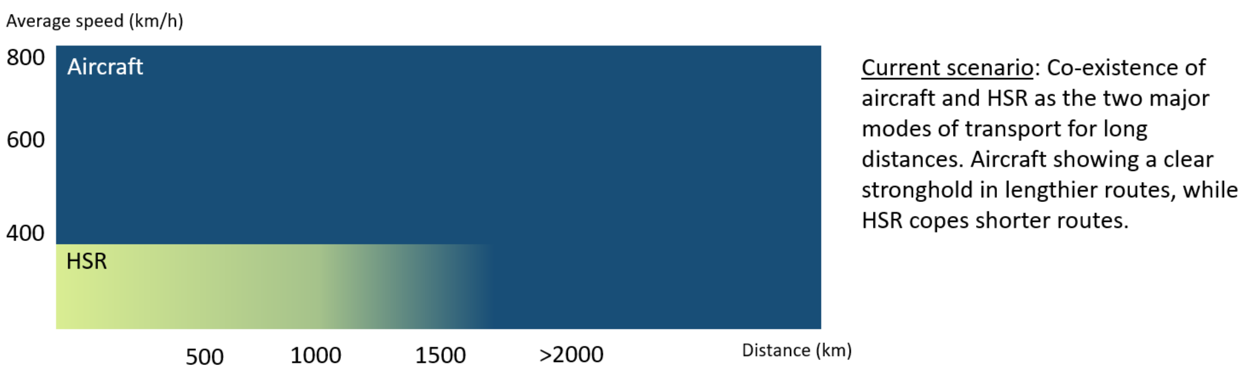
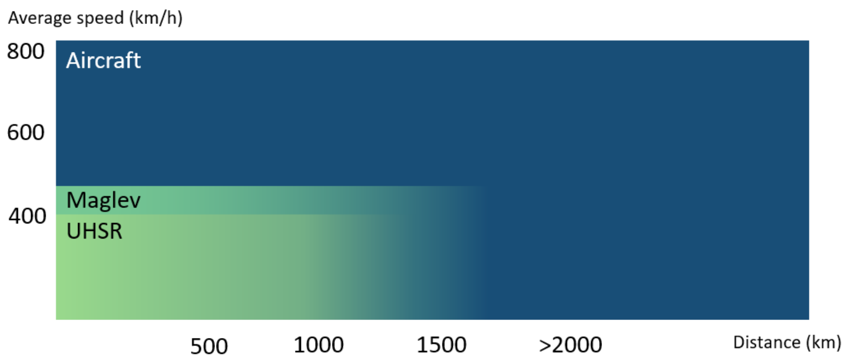


Figure 47. Actual scenario

HSR has had different levels of market penetration: void in the USA, moderate but solid in Europe, champion in China. As discussed during this report and indicated by the UIC (UIC, 2018), SR still has some growth potential in terms of top speed on commercial basis. But not that much on average speed. On the other hand, aviation has wide market penetration worldwide because of it is almost unlimited range. It can decarbonize and integrate some minor improvements of air traffic management and very minor improvements of passenger management within airports. Nothing that affects significantly the total time spent inside the vehicle or the speed during the trip. Hyperloop is a transport solution with the ability of mimicking airplanes in terms of speed if a land alignment is favourable enough, and able to mimic the HSR or maglev elsewhere on the reliability, comfort, and sustainability criteria. In both cases (Figure 48) a "fair" case has been used for aviation since there is great variability on the time spent at each stage, which depends on the operator, flight and city pair.

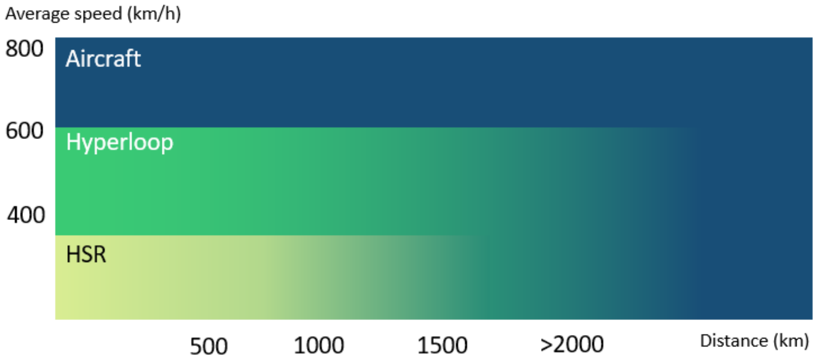
None of these significantly affect the total time spent inside the vehicle or the speed during the trip. Going supersonic is not conceived to serve as a mass-transport system, given its high energy consumption that would make ticket price skyrocket, and available for just a few (Kharina et al., 2018). The combination of both improvement of HSR into UHSR and the potential penetration of Maglev bring and evolved transport toolkit depicted in Figure 49.



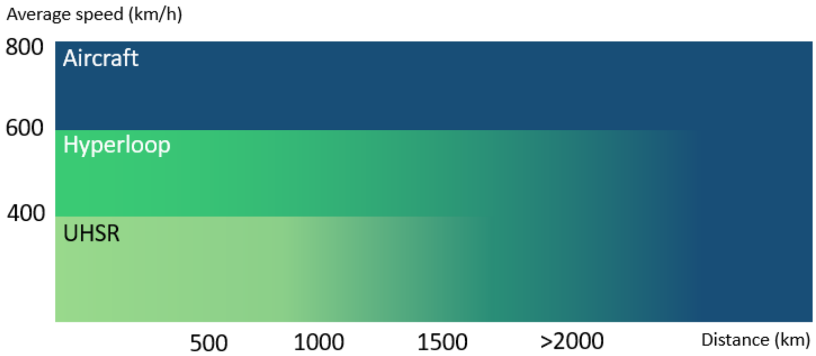
Soft scenario: a soft technological shift happens, with maglev solutions appearing in those UHSR upper limit routes by extending land distances through a better value of time.

Figure 48. Soft scenario - Late adoption of hyperloop

Hyperloop is a terrestrial transportation solution with the ability of mimicking airplanes in terms of speed, if land alignment is favourable enough, and able to mimic the HSR or maglev elsewhere on the reliability, comfort, and sustainability criteria. Below, two adoption scenarios are depicted, showing the case for a continuation of evolving HSR into UHSR or a second where hyperloop takes the role and block future evolutions since it can cost effectively absorb this market share.



Disruptive scenario 1: A strong technological shift happens with Hyperloop given its fast market readiness (2030). UHSR and Maglev are fully discarded, because of their marginal improvements, while all the effort is put towards Hyperloop, boosting land distances and thus, value of time.



Disruptive scenario 2: A strong technological shift happens with Hyperloop, but the slower market readiness (2035-2040) facilitates the development of the UHSR, substituting current HSR, and increasing its competitive distance routes against hyperloop. However, Hyperloop still offers unbeatable value of time in its range domain (<1,500/2,000 km).

Figure 49. Future scenarios - deep hyperloop penetration

Overall, the two depicted scenarios with deep hyperloop penetration, specially the "Disruptive Scenario 2", is selected as the preferred one to happen from a societal point of view and based on all previous explanations on this report. This scenario canvases a real, but only mild, development of the HSR into UHSR, with the decarbonisation of aviation for long haul on the mid-long term and little to no decarbonisation at all in the short-haul routes due to the high-power requirements during the climb phase, which by itself represents more than 33% of the overall mission on a 1,000 km, or more than a 40% on a 750 km (Flightaware, 2021). That niche, where no other solutions are suitable, is the one hyperloop will use for starters in the long-distance route segment, and then grow from there, while the energy storage technology reaches maturity allowing for much longer distances (for the case of hyperloop with onboard energy storage systems). Still, the range of true competitiveness are markets of less than 1,500-2,000km. Then, it can be stated that hyperloop is offering a regional transport solution, greatly dependable upon its market readiness and regulation and customer acceptance.

8.4. Interregional/Intercontinental development

Ultra-long distance refers to distances over 2,000 km. For instance, a case study could be made for the connection between Europe and China. For the purposes of this exercise, the geopolitical risks would not be considered, or the probability of stopping on the line due to the high number of vehicles on the line. Consideration on range and energy storage will neither be addressed at this point. The focus will be on a simplified cost-benefit case of a One Belt-One Road executed using the infrastructure cost of 30 M€/km (**Error! Reference source not found.**). The cost is assumed to remain constant because most of the land is inhabited, thus land acquisition will be significantly cheaper. From a general perspective the terrain is favourable for the deployment: flat, wide, and straight forward in most of the cases. There are some options for the alignment as represented in Figure 50.

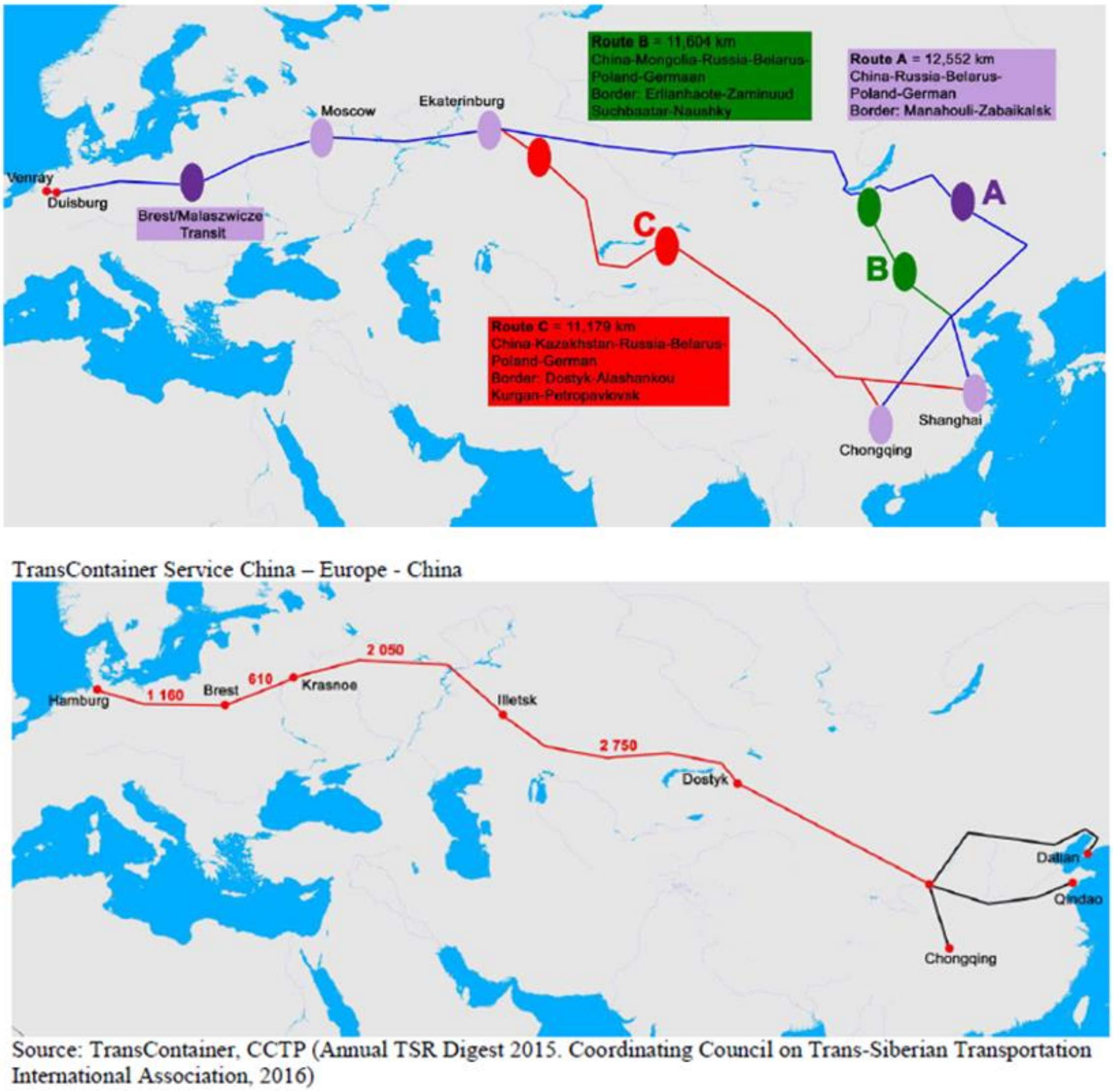


Figure 50. Alignments proposed for a Europe-China connection

For the purposes of the analysis the section between Europe's eastern (Poland) to Urumqi in China will be considered. This route spans for 5,500 to 8,000 km. This considers there is either a hyperloop already functional at both ends or that no need for the hyperloop is needed between both ends. Therefore, the focus will be the main segment whose costs need to be covered. Current demand between both ends is 2 million tons a year (Figure 51), just by air in 2016 (UN-

ECE, 2018). An air demand of around 5 million tons is expected before 2050 between both ends (Figure 51), that could also come from the expected demand of a potential HSR corridor (Kosoy, 2017).

Modes of transport	2011	2012	2013	2014	2015	2016	2016/2011, %
From China to European Union							
- Maritime	50.1	43.5	47.7	52.7	53.8	54.4	108.6
- Air	1.0	0.9	1.1	1.3	1.1	1.2	116.4
- Rail	0.4	0.3	0.3	0.4	0.5	0.6	170.6
Total	51.5	44.7	49.1	54.4	55.4	56.2	109.2
From European Union to China							
- Maritime	38.0	39.5	41.0	41.8	44.5	47.7	125.3
- Air	0.6	0.5	0.7	0.6	0.7	0.8	124.0
- Rail	0.1	0.1	0.1	0.2	0.2	0.4	326.5
Total	38.8	40.1	41.8	42.6	45.4	48.8	125.9
TOTAL between EU-28 and China	90.2	84.7	90.9	96.9	100.8	105.0	116.4

Source: Eurostat

Figure 51. Volume of goods transported between EU and China by mode of transport in 2011-2016, million tons

The revenue achieved by transporting 5 million tons is under the assumptions of air freight pricing ticketing of between 3.6 and 4.5 €/kg (World Bank, 2009). Based on the revenue expected per passenger, a virtual passenger demand, with the cargo pricing set at a moderate 3.60 €/kg, will be equivalent to a virtual demand of 150 million passengers per year. At a 30 M€/km, the most restrictive case requires a demand of 34.3 million passengers for 500km for NPV>0.

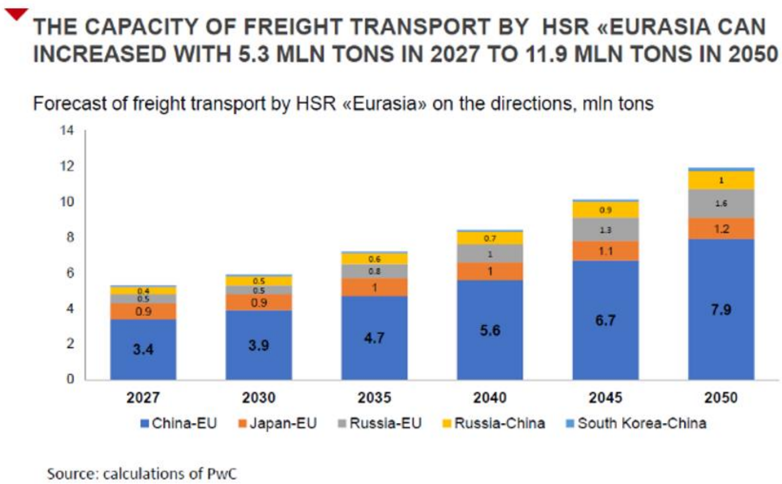


Figure 52. Freight transport increase in the Euro-Asia connection by 2050

Therefore, on the restrictive case, a 2,000 km route will be justified just with those figures. Also, on a favourable case however, 7.2 million virtual passengers for 500 km means the 5,500 km will be not only self-sustainable, but extremely profitable. A variety of cases with a positive outlook appear, even before considering the lower cost of the infrastructure, setting the price at the common 4.00 €/kg, or the possibility of introducing passenger service in some sections of the route. In fact, this could lead to the question on whether the infrastructure could be paid only by cargo. This may foster business between both ends at an unprecedented level due to the combination of speed and cost obtained, benefitting intermediate locations such as Kazakhstan.

9. Transport Demand and Forecast

An initial exploration and assessment of the hyperloop demand is attempted in this section. The passenger and freight demand are analysed and the position of hyperloop to address potential shares is discussed. A feasibility study for potential markets is also performed and summarized by using a case study for Europe to understand the hyperloop potential against other existing, or potential means of transport. Finally, the position of Zeleros within the EU polices and TEN-T network is summarized.

9.1. Passenger transport

In assessing transport demand and forecasts as they relate to the passenger, we will consider three substantive issues.

- First, potential competition between hyperloop and existing modes of travel, and in particular the comparative advantages or disadvantages of hyperloop in terms of fares, journey time and other aspects of journey quality.
- Second, future trends in the market for passenger travel, and specific insights which potentially inform the economic case for hyperloop.
- Third, drawing together the first two sections, we will identify priority areas where further research could help to further understanding of the potential passenger market for hyperloop.

9.1.1. Competitiveness factors

9.1.1.1. Modal competition

As (Taylor et al., 2016) note, in common with other mode competition contexts, travel demand can be conceptualised and analysed in terms of fares, journey time and other aspects of journey quality. The latter could include various aspects of time-related quality such as headway, reliability, and on-board comfort (i.e., time spent in a given level of comfort).

According to (Taylor et al., 2016), Hyperloop is expected to achieve maximum operating speeds of 720-760 mph over distances of 300-500 miles – which is approximately 50% faster than the cruising speed of a typical passenger plane, and three times faster than Maglev. However, these speeds will be moderated by the need for gradual acceleration/deceleration when departing from/arriving at stations. Given this context, it would seem likely that Hyperloop will focus on point-to-point intercity journeys with few or no intermediate stops. Naturally, this would limit connectivity to the network, thereby creating a similar passenger proposition to air, but without the non-trivial taxiing time typically encountered when making journeys by air. This kind of operating context is corroborated by AECOM's feasibility study for Transport Canada (AECOM, 2020).

Additional considerations in terms of travel time, especially when drawing comparison with air, is whether there would be the need to allow access/egress time for security checks and baggage handling/recall, and how boarding/alighting times would compare to air. Last but not least, there is the question of where Hyperloop stations/termini would be located, and thus the implications for access/egress times to the ultimate origin/destination.

All things considered, it would seem likely that hyperloop would achieve a significant reduction in end-to-end journey times, relative to both air and maglev. According to a recent study (Taylor et al., 2016) the example of a journey from Los Angeles to San Francisco was cited, a journey of some 380 miles taking approximately 1.5 hours by air and 2 hours 40 minutes by the proposed HSR scheme, and speculate that hyperloop would achieve a travel time saving of 45 minutes over air and 2 hours over HSR. Bearing in mind that the GB rail industry recommends, via the Passenger Demand Forecasting Handbook, a Generalised Journey Time (GJT) elasticity of -1.2 to -1.35 for long distance flows, this would imply that, if hyperloop can be presented as effectively an enhanced rail offer and thus amenable to analysis using PDFH methods[4], the 2-hour journey time saving would achieve a more than five-fold increase in demand.

9.1.1.2. Frequency and capacity

It is understood that hyperloop could provide a very high frequency of service with service intervals. As mentioned earlier the level of service that the hyperloop can achieve will mainly depend on the size and capacity of the pod, which can be set from 20 to 200 passengers and dispatching a vehicle every 18 seconds to every 2,5 minutes. With as low as every 30 seconds for a pod accommodating 28 passengers. Whilst the high frequency compares favourably with both HSR and air, the implied capacity of 3,360 passengers per hour would be considerably inferior to a high frequency HSR or air service. This would seem to represent a significant constraint on patronage and thus revenue.

It is understood that hyperloop could provide a service with a very high frequency, as low as 18 seconds to 2.5 minutes. The level of service that the hyperloop can achieve will mainly depend on the size and capacity of the pod, which can be set from 20 to 200 passengers. Whilst the high frequency compares favourably with both HSR and air, the hyperloop system capacity can be lower to those of HSR or air service. However, capacity widely varies depending on the world region, or commercial line. For the European case, rail capacities range from 500 to 6,650 pphpd (passengers per hour per direction) (Armitt & Houghton, 2016). However, in Asia, capacities enlarge to values of up to 30,000 pphpd in the Tokaido line in Japan (JR-Central, 2019). For the case of aviation, and for comparison purposes in terms of pphpd, the most demanded route in the world exerts a capacity of 2,400 pphpd (Wikipedia, n.d.). Zeleros hyperloop is developing vehicles in the range of 50 to 200 passengers, that would result on a capacity of 4,800 pphpd,

[4] Strictly speaking, PDFH recommends that these elasticities should not be applied to the case of large GJT changes, so these calculations should be interpreted as cautious upper bound estimates.

with an interval of 2.5 minutes, 200 passenger pods and a single tube. This capacity can compete with aviation and is within the limits of acceptance when compared to railway. However, if a greater capacity is needed, extra tubes could be built.

9.1.1.3. Fares

Without knowledge of the cost base and competitive environment, it is difficult to speculate on the likely fare structure for hyperloop. However, (Taylor et al., 2016) gives an indicative fare of $20 for San Francisco to Los Angeles route, which they suggest would be sufficient to cover operating costs. Once again referencing the recommendations detailed in Passenger Demand Forecasting Handbook PDFH, own-fare elasticities for long distance journeys cover a wide range (-0.5 to -1.45), depending on the ticket type, journey purpose and whether the journey does/does not terminate at the capital city (i.e., London). Whilst these recommended elasticities cover a wide range, it should be said that these recommendations are underpinned by comprehensive and robust empirical evidence. Unfortunately, PDFH does not demonstrate the same level of confidence in relation to recommendations concerning cross- (as opposed to own-) fare elasticities (e.g., in relation to mode choice), since empirical evidence on fare-based competition is notoriously volatile.
Against this background, it is very difficult to make a priori judgments as to the likely own elasticity of demand with respect to the fares for hyperloop, the likely cross elasticity with respect to the fares for other modes, or indeed the basic question of whether an increase in hyperloop fares would (when accounting for drop-off in demand) serve to increase revenue.

9.1.1.4. Comfort

Another focus of the PDFH forecasting handbook developed by the GB rail industry is the impact of changes in comfort on passenger rail demand. On HSR or conventional rail, an enhanced journey in this context would bring the likes of improved seating and legroom, wi-fi connectivity, tables for laptop use, additional toilet facilities and provision of catering facilities, etc. Interestingly, in the case of Hyperloop, it is likely that the in-vehicle experience will be considerably inferior to HSR or indeed conventional rail.

For example, comparing a 2+2 seat with table configuration to an airline seat configuration, PDFH advises that the value of time is 2% lower for business travellers in the former case. Somewhat paradoxically, in the case of Hyperloop, it is likely that comfort will be inferior to both HSR and conventional rail, since it is questionable whether it will be practicable to provide even basic facilities such as toilets. Moreover, hyperloop will likely introduce new dimensions to considerations around comfort. In particular, hyperloop technology will allow significant g-forces on passengers – when the conventional wisdom is that 0.5g is the maximum for human comfort. Another consideration is excessive noise, although data is limited on the levels of noise which hyperloop passengers could be exposed to.

9.1.1.5. Reliability

One area where Hyperloop would seem to have a distinct competitive advantage – especially over air but to some extent over conventional rail also – is its resilience to inclement weather conditions which could affect punctuality and cancellations. That said, and again with reference to PDFH, recommended elasticities of passenger rail demand with respect to lateness are small – in the range -0.07 to -0.115 for most services. This implies that a 1% improvement in lateness would lead to a maximum of a 0.115% increase in demand.

9.1.2. Future rail market trends and the economic case for hyperloop

9.1.2.1. Long distance travel trends

Clearly, Hyperloop is more suited to long distance markets of 300-500 miles. Whilst recent evidence in some European countries (e.g., Great Britain) shows that the total number of trips people make is relatively static, the average distance travelled has been increasing, implying that the propensity to undertake longer distance trips is increasing. This phenomenon has been especially prevalent in the rail sector. In Great Britain, long distance rail travel has grown substantially since 1995, reflecting economic growth as well as improved journey times, headway and reliability. By comparison, domestic air travel has declined, reflecting greater competition from rail and increased out-of-vehicle journey time due to security and check-in times. Despite these trends, rail continues to account for a minority of long-distance trips in Great Britain, most of which are undertaken by road.

More generally, (Aparicio, 2016) reviews long distance travel trends across Europe as a whole, and concludes that “Even under a scenario of ‘peak travel’, total long-distance passenger demand may keep growing, following population trends, but only in some regions in Europe, particularly in the north, and could be further strengthened by global migration flows”. He observes that long distance travel behaviour shows considerable variation across European countries, depending on size of the country, per capita GDP trends and the characteristics of the population. He continues: “Although there are good arguments to conclude that peaking in long-distance transport demand could be reached in an increasing number of European countries, there are also significant forces to further expand demand”.

Against this background, there would seem to be opportunity to add stimulus to the market for long distance travel through the advent of hyperloop, but this opportunity is clearer and more compelling in countries where there continues to be growth in the long-distance travel market.

9.1.2.2. Specific feasibility studies

Interestingly, according to (Taylor et al., 2016) , several specific Hyperloop projects currently are being developed at the feasibility stage, and alongside US examples, a number of European examples are also covered, as follows:

- Vienna, Austria - Bratislava, Slovakia - Budapest, Hungary. Current journey time by train or bus from Bratislava to Vienna is 1 hour, and this would be reduced to 8 minutes by hyperloop. Similarly, the journey from Bratislava to Budapest would take 10 minutes.
- Helsinki, Finland - Tallinn, Estonia. The construction of a tunnel across the Gulf of Finland would link these cities which lie 31 miles apart.

Taylor et al. suggest that the strategic and economic cases for such schemes are especially persuasive where hyperloop connects a city with “an existing transit network and low housing costs but perhaps few employment opportunities to a city with high housing prices and abundant jobs”. As well as the above cases, the authors also speculate that a link between Denmark and Sweden might be justified on a similar basis.

9.1.2.3. Revenue forecasts

As noted above, it remains to be seen what fare structure will underpin hyperloop. However, a recent scoping exercise undertaken by transport consultants (Judge, n.d.) sketched out a possible scenario as follows. They assume that air capture represents the best commercial opportunity for hyperloop, and on that basis undertake some rough calculations by referencing against current air fares. More specifically, they consider the same case study introduced earlier of Los Angeles and San Francisco, and undertake the following calculations:

- Assuming 12.8M passenger journeys per year and a fare of US$135 per one-way trip gives rise to total passenger market value of US$1,700M in 2017 prices.
- Assuming 1,100km/h average speed and convenient terminal stations, the introduction of hyperloop serves to generate an additional 17% hyperloop/air traffic and captures 70% of the ex-ante air market. The corresponding figures fall to 9% and 61% if the average speed of hyperloop falls to 500km/h; and to 5% and 55% if stations are sited in less convenient locations, all else equal.

9.1.3. Priority research areas

Informed by the above discussion of sections 9.1.1 and 9.1.2 we would highlight the following as important areas for further research seeking to better understand the potential passenger market for hyperloop.

- Establish a definitive demand forecasting approach/methodology for hyperloop, such that alternative schemes are analysed in a comparable and consistent manner. This approach would focus on the most important features of the journey experience (e.g., fares and journey times), be amenable to the analysis of competition with rail and air, and be readily tractable using available industry data at the European level.
- Undertake willingness-to-pay (WTP) research to better understand the key trade-offs, e.g., journey time vs. fares vs. comfort, inherent within the competitive environment for hyperloop. A particular focus would be to determine whether existing understanding of such trade-offs, e.g., such as the value of travel time savings, can be readily extrapolated to hyperloop, or whether there are idiosyncrasies of Hyperloop that introduce new dimensions to such trade-offs.
- Following from the previous point, it could be instructive to undertake focused behavioural research, to better understand the perceived advantages (e.g., speed) and disadvantages (e.g., noise and comfort) of hyperloop from the passenger perspective.

9.2. Freight transport

The demand for transport and mobility in Europe, as well as in the rest of the world, is increasing annually, and its decline in the long term seems unlikely (European Environment Agency, 2021). At the same time the necessity to reduce emissions by switching to more environmentally friendly modes of mobility is increasing, and this is one of the main objectives of EU transport policy. On the one hand this presents a challenge for conventional means of transport and mobility, on the other hand a potential for innovative solutions.

Currently, five countries are responsible for more than two-thirds of European air traffic (i.e., UK, Germany, Spain, France and Italy). In both sectors, cargo and passenger, there is a lack of infrastructure availability. Demand for air transport is growing faster than airport capacity. In addition, aviation emissions are the highest of all modes of transport (Alves, 2020). In Figure 53 the overall air freight transport is shown for the EU over ten years.

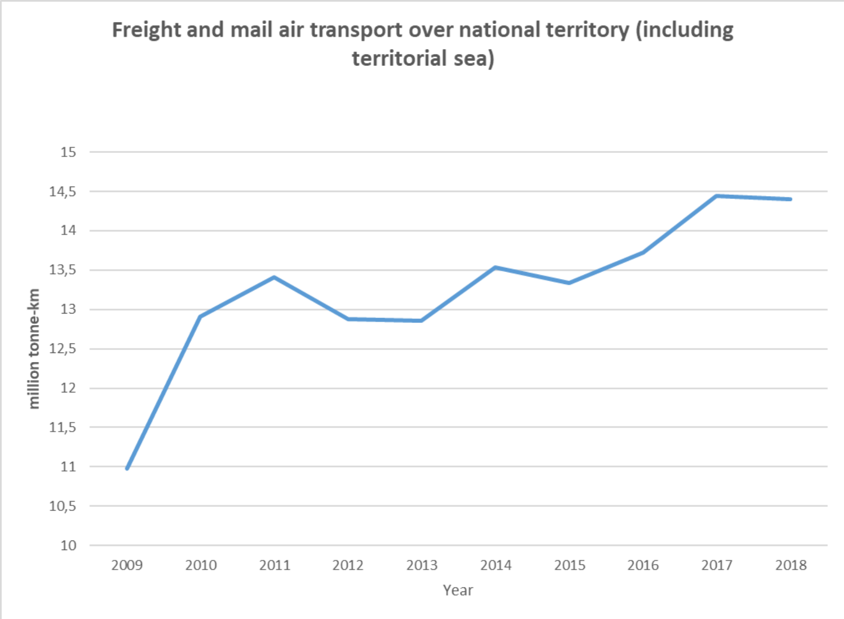


Figure 53. Air freight and mail transport over national territory (Eurostat, n.d.)

Rail transport is one of the most popular types of intermodal transport of goods. Despite the annually growing demand for international rail transport (see Figure 54) there are many problems, such as irregularity of infrastructure on some routes, problems with service and coordination of international transport that cause inefficiencies and delays (e.g., Portugal and Spain). Still rail is one of the most efficient means of transport in terms of low emissions (Lewis et al., 2001).

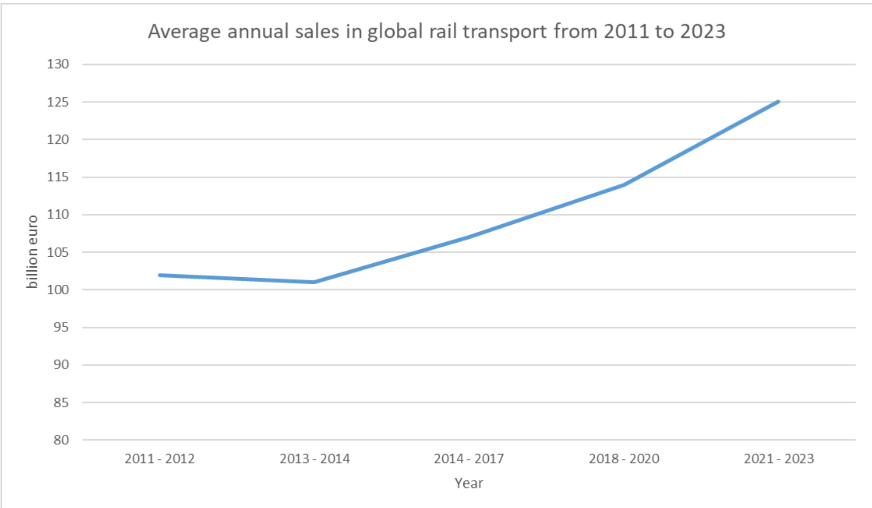


Figure 54: Average annual sales in global rail transport from 2011 to 2023 (Statista, 2021)

According to Eurostat data, more than 50% of freight traffic is handled by the road segment (Eurostat, n.d.) (Figure 55). The competitive advantage of this type of transport is flexibility (they allow door-to-door delivery), as well as the combination of delivery speed and its cost. However, it has the highest CO_2 emissions compared to the other modes of transport.

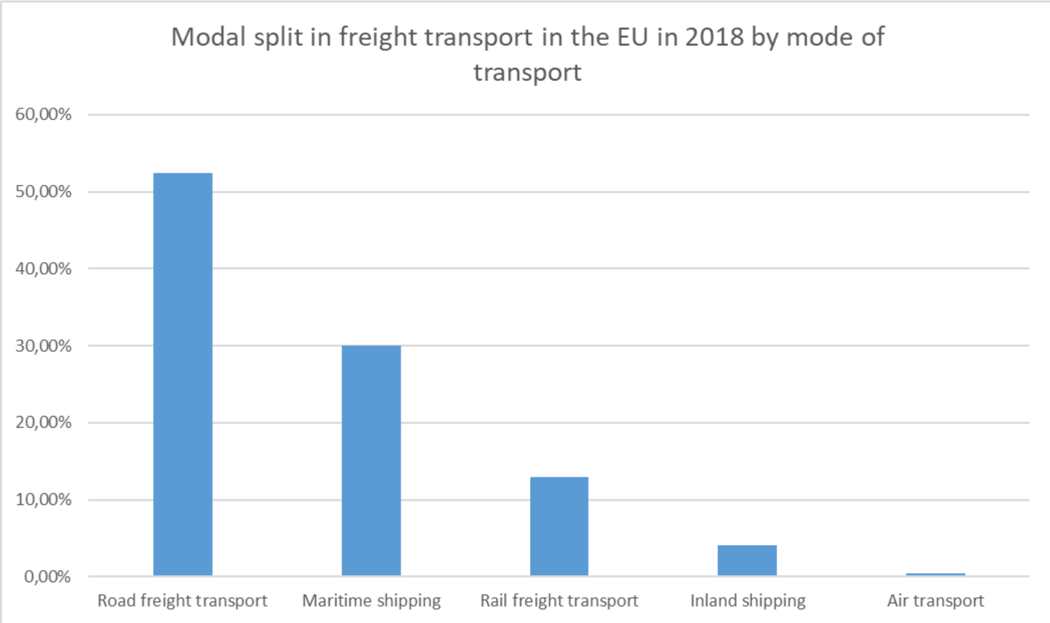


Figure 55: Model split in freight transport in the EU in 2018 by mode of transport (Statista, 2021)

Maritime transport in recent years, unlike other types of transport, does not show stable growth. To be effective, this transport needs to achieve economies of scale. Transport in this segment is less reliable due to such problems as port restrictions and weather conditions. The main advantages are capacity and the ability to serve routes separated by seas and where there is no rail and road connections (Van Der Horst & De Langen, 2008).

To evaluate the potential of hyperloop, it is necessary not only to consider the demand for different modes of transport, but also to understand the desired characteristics of the shipment. These include cost of transport, average delivery time, flexibility, possible frequency of transport (more frequent delivery reduces inventory and thus costs), reliability, as well as type of cargo and length of transport (Werner et al., 2016).

One of the main competitive advantages of the Hyperloop compared to other modes of transport is the speed. Its average speed is estimated at 900 km/h, while in air transport is 500-800 km/h. In addition, hyperloop stations are planned to be located in the city centres (unlike the airport), which also reduces the delivery time to a location in the cities (DPWorld, 2021).

Another advantage is the frequency. It is assumed that hyperloop will be able to depart every 2 minutes on average. This is the highest frequency of departures among long-distance deliveries. This increases the flexibility of freight transport. It is also assumed that the cost of tickets for passengers on the hyperloop will be quite low. This can also be extrapolated to the freight transport segment. For example, according to experts from the Mid-Ohio Regional Planning Commission, a ticket from Pittsburgh to Columbus (about 300 km) will cost $33 (MORPC, 2020). Applied to shipments which are easy to handle, this means low costs for a comparable distance.

Hyperloop involves a unique combination of competitive advantages. It is a clean mode of transport, as well as having the flexibility and accessibility mainly provided by road freight in combination with high speed comparable to air transport.

The main disadvantage relates to the investments for new infrastructure which entail significant costs. Due to the high costs, it makes sense to place the new infrastructure on routes with high demand. In view of its high speed, the hyperloop has its greatest interest on middle to long distances (e.g., 300 - 500 km), with longer distances being possible. Travel distances of less than 300 km would not allow for speed advantages (Alves, 2020).

One possible way to reduce the implementation costs is to partially use existing infrastructure, such as airports, train stations, and ports, for example, when incorporating hyperloop into intermodal supply chains. This would not only reduce the cost of building the necessary infrastructure, but also increase the efficiency and speed of these chains.

9.3. Market assessment for long-range routes

Throughout this report, hyperloop capabilities are discussed within the industry framework to understand the market niche of the solution against other existing, or potential, means of transport. Hyperloop is regional in nature, and competitive at connections of up to 1,500 km. Considering specifications such as the minimum headway, capacity of the vehicle or average speed, to name a few, a Total Addressable Market (TAM) is conducted for each world region (Figure 56). It represents a maximum number of routes and corridors: 110,000 km of hyperloop routes, with the most prominent regions being Europe, North America (USA mainly), South Asia (India) and East Asia (China).

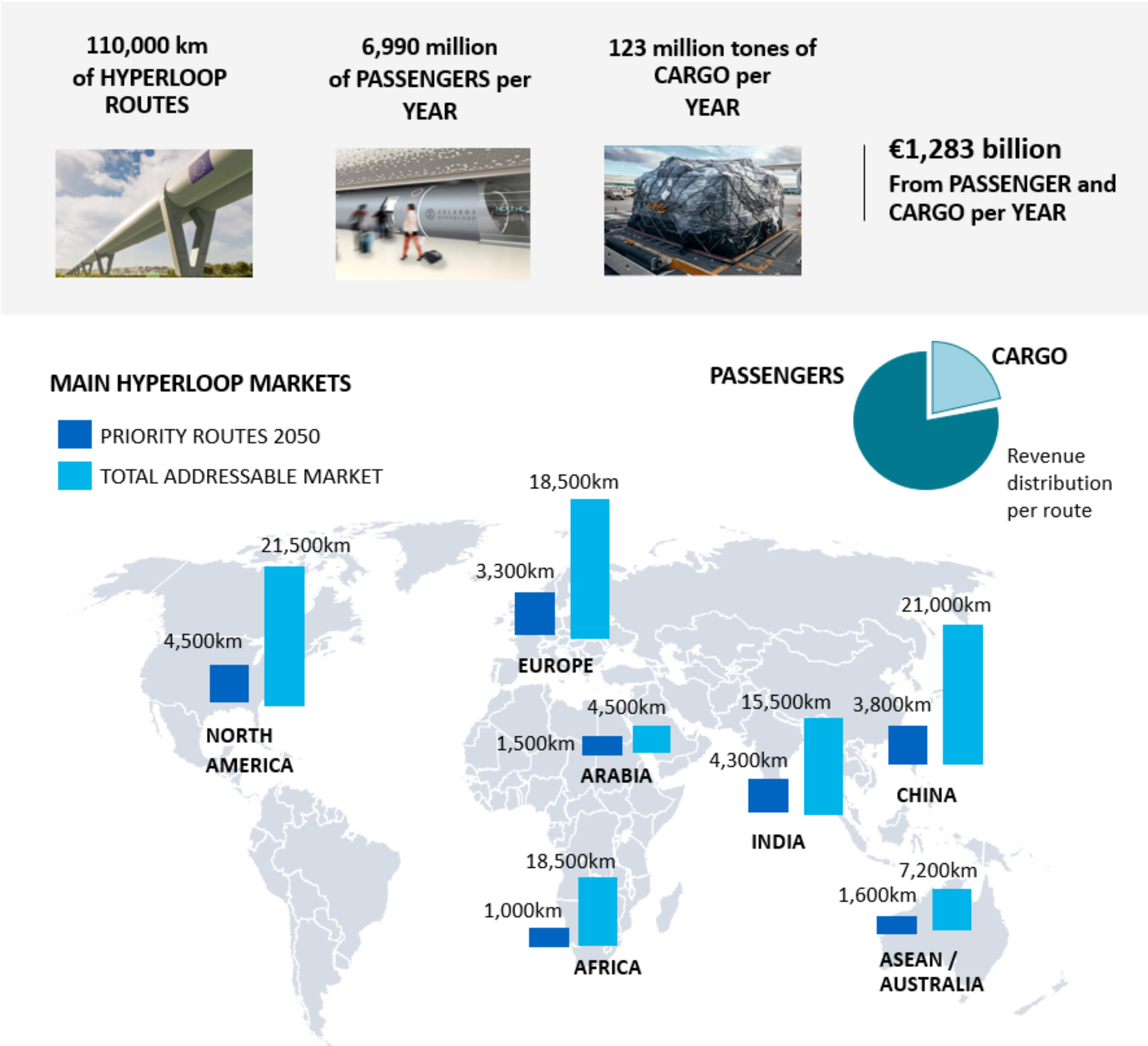


Figure 56. Total available market and priority routes 2050, key figures

In addition, an unconstrained demand condition has been added to the model to showcase the raw system potential in terms of capacity, and some key revenue figures, in a simplified manner. This means, the capacity is affected by factors such as vehicle size (passengers per vehicle) and the headway, referring to the time needed between two consecutive vehicle launches. The results of the TAM are a capacity of near 7 billion passenger seats transported per year, plus over 120 million metric tons of cargo. This entails a market valuation, just in terms of direct revenue for operators, of over 1,200 billion euros.

Assuming hyperloop is accepted by operators and end users, four market development scenarios are foreseen: no adoption, early market adoption, late market adoption, and adoption discontinued. Since hyperloop is a regional transport solution, it could fully succeed in some regions and totally fail in others: specific regional factors will play a significant role on this regard, hence variability goes beyond the few simple cases here explained:

- **No adoption:** policies, technology, market, acceptance, or a weighted mix contribute to the failure of the solution's deployment. Hyperloop is not developed beyond full scale prototypes, even if it becomes certified for operation.
- **Early market adoption**: hyperloop development meets a planned technology and regulation roadmap, backed by regional policies on its deployment, together with funding. The solution receives public acceptance timely. No matter how smooth all these conditions are, by 2050 there is a sufficiently wide network showing the potential for scaling up, and a wide number of projects are on backlog ready be deployed.
- **Late market adoption**: hyperloop development completes a technology and regulation roadmap, backed by regional policies on its deployment, together with funding. However, heavy lobbying against hyperloop is carried out from aviation and the rail industry. Product receives public acceptance once it is ready, and not before. By 2050 there are enough lines operational that only indicate a positive trend. There might even be a backlog of projects on the verge of being triggered, but some caution holds them from starting until there is further reassurance.
- **Adoption discontinued**: despite the initial success of hyperloop, policies and technical development of the Ultra-HSR, clean, or even supersonic aviation, lock-in the hyperloop development. The hyperloop is discontinued and superseded, and only a few lines remain operational until they complete their lifecycle or are even decommissioned earlier than required under a sunken cost perspective.

Given that the early market adoption or late market adoption are the scenarios preferred for the hyperloop development, a set of potential routes arise from the Total Addressable Market as the ones to be deployed by 2050 given their potential market and societal benefit, called priority routes 2050 (Figure 57).

Figure 57. Priority routes 2050

These routes represent a total of 20,000 kilometres (out of the full potential of 110,000km globally) and currently have high levels of demand, magnifying the decarbonisation effect by replacing current airplanes. However, it must be considered that the regional perspective of the solution provides unique qualities to each market, hence development at each one may have a:

- very different construction start date.
- very different construction pace.
- very different time to achieve breakeven.
- very different time to achieve full operational potential.

While the Total Addressable Market (110,000 km) is not really constrained by a time horizon, the priority routes 2050 represent the result of the first deployments. Considering the list of factors indicated above, the problem is not the start date, but the date at which all priority corridors are built, to provide a meaningful evaluation at a global scale. Here, global deployment starts at 2030, with the priority routes horizon set at 2050.

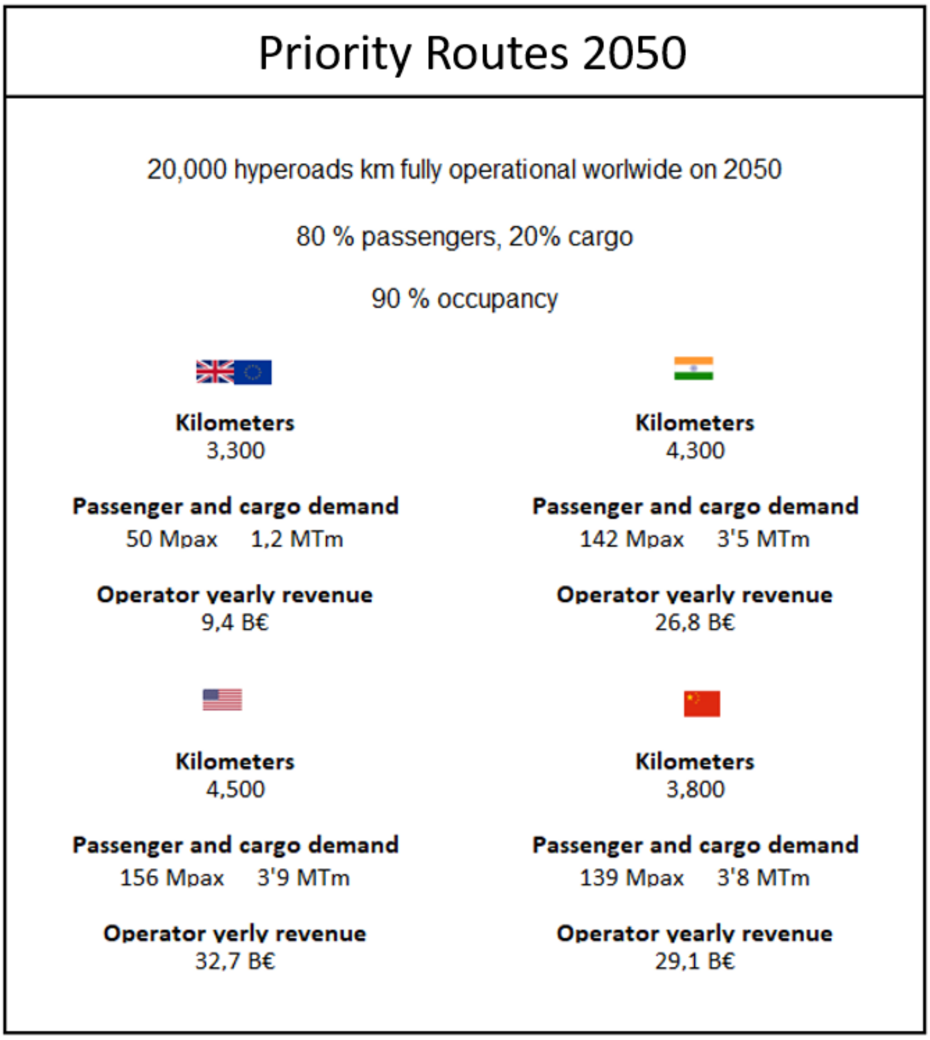


Figure 58. 2050 priority routes

The next step is to explore the feasibility of the solution from the economical point of view. It is important to recall that infrastructure will cope 95% of the project's cost, becoming the true driver. Figure 58 shows four regions representing a similar number of kilometres and similar volume in terms of opportunity for operators: Europe, North America, China, and India. The case of Europe has been selected to explore market opportunities generated by a long-distance hyperloop network in the coming decades.

9.4. The European priority hyperloop networks

The route in Figure 59 connects 6 countries, 5 within the EU and one outside (UK).

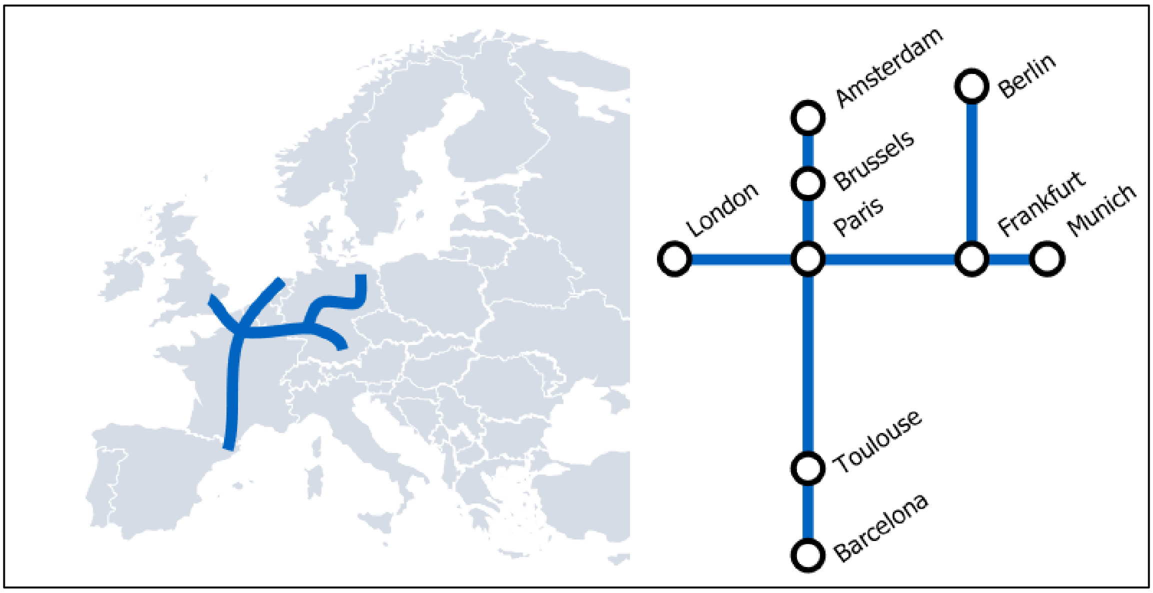


Figure 59. European high priority routes

The priority European network will virtually totalize 3,300km. Investment in high-speed lines is only justified if high-speed yields can be achieved: the larger the population base (future demand) and the greater the travel time elasticity and speed yield, the greater the benefits of developing a high-speed line. Elasticity relates to the willingness of potential passengers to alter their behaviour in response to changes in travel time: high travel time elasticity indicates that passengers are willing to switch to rail when travel times are improved (ECA, 2018). For the proposed priority route, it is relevant to note the addition of a modern version of Eurotunnel, made by 50-80km that would unlock vast potential in term of network effect and total demand for the passenger transport.

To calculate potential demand, the following assumptions are made:

Air transport

- Based on Eurostat (Eurostat, 2021), air traffic in 2019 between all cities indicated was 48.6 million passengers
- The demand in 2019 has been assumed to be the same demand in 2035. This means the demand forecasted for 2035 is 48.6 million passengers.
- The demand is escalated from 2035 to 2050 based on Eurocontrol's projection for the traffic in 2040 with the 2017 baseline (Eurocontrol, 2018), as illustrated in Figure 60. A traffic increase over the affected countries of around 1.5% between 2035 and 2050. This forecast is therefore:

  - Pre-COVID 19
  - Only up to 2040, while horizon is 2050.
  - Based on all airports, not only the ones in the line. On the other hand, those on the line are those of the largest city and airports in Europe: Frankfurt, Barajas, Charles de Gaulle, Schiphol, Heathrow.
- It is assumed that hyperloop will capture 90% of these passengers.

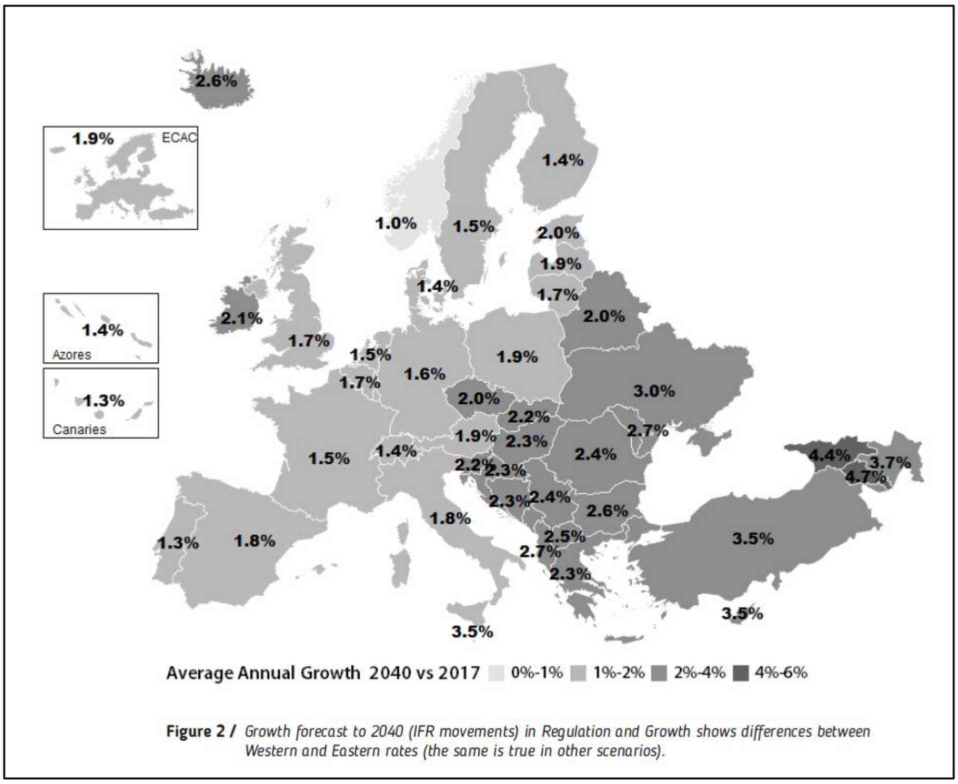


Figure 60. Air traffic growth in Europe: 2017 vs 2040 (Eurocontrol, 2018)

Rail transport

From the rail service, a total of 21 million passengers could be identified on these routes in 2019, and again, they have been considered as the baseline demand in 2035. These are mostly High-Speed Rail passengers travelling on international routes, such as the Eurostar, that adds more than 11 million to this accrue (Global Railway Review, 2019), and has a potential growth to reach 16 million by 2037 (Department for Transport (UK), 2007). The Thalys service (IRJ, 2017) (Figure 61), where just trips between Amsterdam, Brussels and Paris were considered. The forecast ridership of the Eurostar (Figure 61) needs to be taken with caution given previous forecasting attempts (Eurostar, 2014; HS2, 2012), but still depicts a strong positive trend particularly on a 2050 scenario basis.

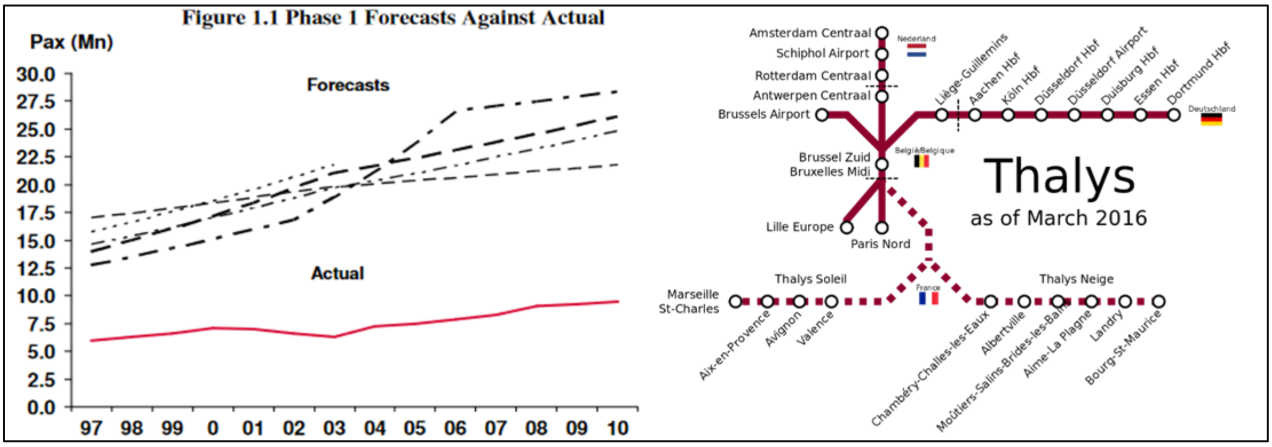


Figure 61. Eurostar ridership forecast (left). Thalys service route map (right) (IRJ, 2017)

It is assumed that only a 25% of these train passengers will be diverted to hyperloop. This is to highlight that, particularly in short services like Paris-Brussels, the modal shift will be minimal and mostly focused on business travellers catching the opportunity of an even faster service. As in the air assumptions, a yearly 1.5% increment is applied for rail between 2035 and 2050. Finally, a 1% induced demand has been added to the calculation. This means that once the demand of air and rail for 2050 is obtained, the outcome is divided by 0.99, which results on a small increment of 1.01%. The total demand is forecasted to be 62 million passengers.

It is important to underscore the small contribution to the overall demand coming from rail, accounting to a 10%. It is also interesting to visualize that by 2035 the English Channel tunnel would be operational for already more than 55 years, and by 2050 for more than 70 years.

The cargo demand is more unpredictable given the disruptive nature of the solution. Therefore, the following assumptions are made: the offer of seats and cargo capacity, together, will result on an *equivalent* 62 million seats, with a share of 80% for passengers and a 20% for cargo. This means that from the 62 million *equivalent* seats, 49.6 million (62*0.8) will be passenger seats, and the remaining will be cargo, representing a 12.4 million *equivalent* seats. To convert from *equivalent* seats to cargo: one *equivalent* seat equals 100kg of cargo. Therefore, 12.4 million seats will represent 1.24 million tons of cargo (t). Additionally, it must be noted that: Air passengers in 2019 reached 48.6 million passengers and it is expected that hyperloop passengers in 2050 will reach 49.6 million passengers. This is an important remark, as it gives a sense of proportion related to the deployment, estimated for hyperloop. Therefore, it can be concluded that the transport scenario, in terms of passenger volume, is not optimistic, and rather neutral in terms of potential demand. The increment of demand has been transformed directly to cargo, with a mild result of 1.24 million tons considering the trends on air cargo, that hyperloop could absorb.

The contribution of cargo is however particularly important in terms of revenue. For instance, considering that, on a regular basis, a one-way ticket of 100 Euro (2020 prices) covers the transport of a 100 kg (representing a passenger), transporting the same mass of cargo, however, may provide 400 Euro, according to the World Bank (World Bank, 2009): for every kilogram of cargo, typically 4.00 Euro are collected. A more moderate assumption of 3.00€/kg of cargo will be used for the calculation. This means that, in terms of volume, transporting 1.24 million tons of cargo is equivalent to transporting some 37.2 passengers. Therefore, in terms of revenue, the *virtual* passenger demand is: [48.6 + 37.2 = 86.8 million virtual passengers].

To support the statements in the section below, a calculation base has been extracted from the reference document (de Rus & Nash, 2007). This document has a clear focus on HSR, but the inputs can be mirrored for a hyperloop line. The only difference is that the charts focus on a 500 km, where HSR is clearly competitive, while the hyperloop priority European route is 4,000km. The hyperloop case is built through the following ratio: [*yearly million (virtual) passenger demand / total network thousand kilometres* = 87 / 4 = 21.75]. And if a 1,000 km represent a ratio of 21.75, then 500 km represent 10.87.

The cost-benefit analysis for HSR can be transposed to the hyperloop case since the inputs are the same: infrastructure cost/km, value of time increment, debt interest rate, etc. Thus an equivalent 500 km line of hyperloop built at 30 M€/km cost will require for Net Present Value, NPV > 0 on its first year of operation. Under different conditions (such as the interest return rate and the value of time saving achieved), between 7.2 and 34.3 million passengers when infrastructure cost (I) is set at 30 M€/km and the increment in the value of time is between 20€ and 45€, depending on the route length and the specific alternatives. Furthermore, the interest rate of the loans are considered to be 3% or 5%, (Figure 62) (de Rus & Nash, 2007).

First year demand thresholds for NPV>0
(r=5% T=40 C_t=32.5 C_q=91.5 C_c=62)

		Q_t											
		α											
		20%			30%			40%			50%		
		θ											
I	vΔt	2%	3%	4%	2%	3%	4%	2%	3%	4%	2%	3%	4%
12	20	14.9	12.8	10.8	14.6	12.5	10.5	14.3	12.2	10.2	14.0	11.8	9.9
	30	10.0	8.5	7.2	9.8	8.3	7.0	9.5	8.1	6.8	9.3	7.9	6.6
	45	6.6	5.7	4.8	6.5	5.5	4.7	6.4	5.4	4.5	6.2	5.3	4.4
20	20	23.5	20.0	16.9	23.2	19.7	16.6	22.9	19.4	16.3	22.6	19.1	15.9
	30	15.7	13.4	11.2	15.5	13.2	11.0	15.3	12.9	10.8	15.1	12.7	10.6
	45	10.5	8.9	7.5	10.3	8.8	7.4	10.2	8.6	7.2	10.0	8.5	7.1
30	20	34.3	29.1	24.5	33.9	28.8	24.1	33.6	28.5	23.8	33.3	28.2	23.5
	30	22.8	19.4	16.3	22.6	19.2	16.1	22.4	19.0	15.9	22.2	18.8	15.7
	45	15.2	12.9	10.9	15.1	12.8	10.7	15.0	12.7	10.6	14.8	12.5	10.5
40	20	45.0	38.2	32.0	44.7	37.9	31.7	44.4	37.6	31.4	44.1	37.3	31.1
	30	30.0	25.5	21.4	29.8	25.3	21.2	29.6	25.0	20.9	29.4	24.8	20.7
	45	20.0	17.0	14.2	19.9	16.8	14.1	19.7	16.7	14.0	19.6	16.6	13.8

First year demand thresholds for NPV>0
(r=3% T=40 C_t=32.5 C_q=91.5 C_c=62)

		Q_t											
		α											
		20%			30%			40%			50%		
		θ											
I	vΔt	2%	3%	4%	2%	3%	4%	2%	3%	4%	2%	3%	4%
12	20	11.1	10.0	7.7	10.8	9.7	7.4	10.5	9.4	7.1	10.2	9.1	6.8
	30	7.4	6.7	5.1	7.2	6.4	4.9	7.0	6.2	4.7	6.8	6.0	4.5
	45	4.9	4.4	3.4	4.8	4.3	3.3	4.7	4.2	3.2	4.5	4.0	3.0
20	20	17.2	15.0	11.8	16.9	14.7	11.5	16.5	14.4	11.2	16.2	14.1	10.9
	30	11.4	10.0	7.9	11.2	9.8	7.7	11.0	9.6	7.4	10.8	9.4	7.2
	45	7.6	6.7	5.2	7.5	6.5	5.1	7.4	6.4	5.0	7.2	6.2	4.8
30	20	24.8	21.2	16.9	24.4	20.9	16.6	24.1	20.6	16.3	23.8	20.3	15.9
	30	16.5	14.2	11.2	16.3	13.9	11.0	16.1	13.7	10.8	15.9	13.5	10.6
	45	11.0	9.4	7.5	10.9	9.3	7.4	10.7	9.2	7.2	10.6	9.0	7.1
40	20	32.3	27.5	22.0	32.0	27.2	21.6	31.7	26.9	21.3	31.4	26.6	21.0
	30	21.6	18.3	14.6	21.4	18.1	14.4	21.1	17.9	14.2	20.9	17.7	14.0
	45	14.4	12.2	9.8	14.2	12.1	9.6	14.1	11.9	9.5	14.0	11.8	9.3

Q_t: total demand (millions of passenger-trips)
α: proportion of generated traffic
θ: annual growth rate of net benefits
v: average value of time (€/hour))
Δt: average time saving per passenger (hours)
I: investment cost per kilometre (construction + NPV of rolling stock, € millions)

r: interest rate
T: life of the project (years)
C_t: annual fixed maintenance and operating costs (€ millions)
C_q: annual maintenance and operating cost variable with Q (€ millions)
C_c: annual variable cost of the conventional mode (€ millions) C_c=1/2(C_t+C_q)

Figure 62. Demand required for an NPV>0, with interest rates of 3% and 5%

The infrastructure cost must not surpass the 30 M€/km (**Error! Reference source not found.**). Even with 40 M€/km it may financially work, but chances are reduced proportionally to the total Capital expenditures (CapEx) increase. Therefore, the high-pressure approach seems to fit better for this type of a market.

- If the whole network is not fully operational, the network effect and the long-distance journeys replacing airplanes are minored. Demand figures will drop smoothly when only portions of the network are built. In addition, planning and construction pace in Europe can be considered as slow, and therefore debt repayment may become a potential burden.
- NPV>0 within the first years of operation will be challenging since the system will have to go through the wide public acceptance phase first, what might take weeks or years.
- The associated benefits of environmental impact might be underestimated based on current trends, since hyperloop is today less favoured than what it should in the 2050 scenario. Air traffic capacity release should also be considered, same as the reduction on oil dependency, among others.
- Station construction was not included within the calculation (same as for the reference paper calculations (de Rus & Nash, 2007).
- The demand projections can be considered neutral. The main assumption taken is the 90% shift from short-haul aviation to hyperloop, something that at least during the first years of operation, seems a challenge. However, what the calculation does consider is that the transition starts happening when the line opens for service (between 2030 and 2040 on a fully operational manner) and by 2050 the hyperloop becomes the solution of choice. Hence, the demand in 2050 is not a modal shift, but a consolidated hyperloop demand in terms of passengers. The effort is not to demonstrate the ability of a first line to be profitable because, contrary to rail evolutions, the introduction of hyperloop happens in parallel with other competitive factors and a proof of reliability and safety would be required, therefore, it becomes impractical to judge the solution on a first year NPV factor.
- In terms of cargo, hyperloop brings a differential opportunity provided HSR is not being used to cope with this market. Serving cargo transport would imply a relevant opportunity to boost the cost-benefit estimations. The analysis shows that in terms of cargo, hyperloop would also absorb traditional aviation products, such as:

    - Spare parts for land vehicles
    - Spare parts for the aerospace industry
    - Perishable food
    - Materials for fairs and events
    - Plants
    - Drugs, vaccines and pharmaceutical products
    - Live animals
    - Luxury products
    - Artworks
    - Machinery and accessories for medical use.

A European hyperloop network has the potential to be attractive not only for public funding entities but for private endeavours aiming to take advantage of the future profits generated with the exploitation of the system. On the other hand, the other 3 regional markets (USA, China, and India) have a much higher margin in terms of potential demand and the opportunity from a purely private ownership perspective is much easier to demonstrate. For instance, in the case of the more developed transport economies of North America or China, for the 500 km the NPV>0 ratio would be 34.12 and 31.84, respectively. Given a cost of infrastructure of 30M€/km and the more demanding case of VAT=20€ and r=5%, the outcome of the ratio results on 34.3. This ratio does not fully address the hyperloop exclusive benefits, since the reference paper considers HSR only. In any way, both regions clearly show a huge potential.

It is of particular interest to consider that, despite the big differences between the USA and China in terms of internal infrastructure policies, land owning, wages, subsidies, and transport policies for long distance (the US on a mostly private manner through aviation while China on mostly public driven manner through HSR), both markets display similar properties. In the case of Europe's key differential factor, with a centric position in terms of infrastructure policies (public-private mix), and transport policies (aviation and HSR mix), is a *not-as-big* baseline demand.

Finally, it should be noted that the long-term results at every region might differ for many different reasons: e.g., hyperloop could develop beyond the current Total Addressable Market in India, and not even get the priority routes fully deployed in China.

9.5. Alignment of the hyperloop system with policies

Europe is the third market opportunity among the top 4 regions. This can be offset by the strong alignment of both the product and the service of hyperloop with European mobility policies.

9.5.1. Product alignment

According to the European Union Agency for Railways (ERA) (European Union Agency for Railways, 2020), prospects for a feasible uptake (soft/hard innovation) should have the final customer at the centre (whomever it might be, client or user). The ERA requires the following:

- Focus on what will help the railways in their new role. Avoid wasting time and money provoking a modal shift in areas where railways are inherently weak.
- Evolve from technology driven to demand driven.
- Minimize the railway specific solutions, minimize the subject specific solutions.
- Move towards less infrastructure (e.g., No need for catenary where hydrogen cells are sufficient to fuel the trains) and more mobile intelligence (e.g., Transfer of functionalities to on-board).
- Develop the multimodal approach for the benefit of end-users and citizens.

The hyperloop is a hard innovation whose technology leap need is offset by its huge benefits, because, from its inception, it includes all mobility criteria that spring from customer demands: clients, users and even non-users that are affected by the presence or operations of the system, and accounts for the societal demands given the strong focus on sustainability. Hyperloop fits into the ERA requirements given that:

- Based on its superior speed ability, it looks for a modal shift where rail is and will be weak, but aviation is not strong, in terms of performance.
- It has a strong demand driven approach.
- It looks for standardisation of solutions on early design phases.
- It moves towards a less infrastructure-dependant system: no need for catenary, hydrogen cells, and more mobile intelligence by transferring on board functionalities; Zeleros infrastructure is essentially a passive enclosure containing just a (magnetic) rail.
- It is consciously positioned within the mobility framework, not as a spontaneous solution valid for all situations, but rather fostering multimodality with a mobility as a service mindset, and for the benefit of the users and citizens.

9.5.2. Service alignment

The Trans-European Transport Network (TEN-T) policy addresses the implementation and development of a Europe-wide network of railway lines, roads, inland waterways, maritime shipping routes, ports, airports, and railroad terminals (Figure 63). The ultimate objective is to close gaps, remove bottlenecks and technical barriers, as well as to strengthen social, economic, and territorial cohesion in the EU. The current TEN-T policy is based on Regulation (EU) No 1315/2013. Besides the construction of new physical infrastructure, the TEN-T policy supports the application of innovation, new technologies and digital solutions to all modes of transport. The objectives are an improved use of infrastructure, reduced environmental impact of transport, enhanced energy efficiency and increased safety. TEN-T comprises two networks 'layers':

- The Core Network includes the most important connections, linking the most important nodes, and is to be completed by 2030.
- The Comprehensive Network covers all European regions and is to be completed by 2050.

The backbone of the Core Network is represented by nine Core Network Corridors, which were identified to streamline and facilitate the coordinated development of the Core Network. Two horizontal priorities, the European Rail Traffic Management System (ERTMS) and Motorways of the Sea, complement these. Oversight of the Corridors and of the two Horizontal Priorities lies with European Coordinators, nominated by the European Commission.

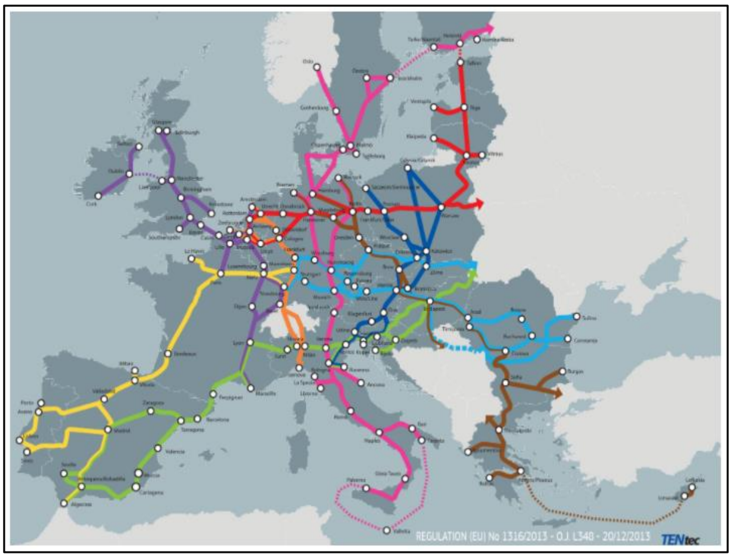


Figure 63 TEN-T Network (TEN-T, 2013)

Because of the fact that hyperloop provides new capabilities, the hyperloop network may, in some world markets, serve as a completely different set of regions and cities (Central Europe may not allow that much differentiation). But clearly, using the speed as a resource, it could connect different regions in Spain, France, or Italy, to name a few. This additional hyperloop layer could provide a different benefit to the EU, the UK, Switzerland, Norway, or Russia. Furthermore, there is a clear budgetary opportunity after 2030, once the TENT-T Core Network is completed, the date when most of hyperloop private promoters expect to be certified for operation. Another budgetary opportunity arises again after 2050, once the TEN-T comprehensive network is fully deployed, which particularly matches the 2050 Priority Routes horizon for its priority routes. After 2050, budget could be allocated more easily to continue the development of the priority routes towards the Total Addressable Market network opportunity beyond the 20,000 km.

9.5.3. End users and customers

Hyperloop could become the solution of choice for customers in routes from 500 km onwards, with an optimum between 750 and 1,250 km, and remaining competitive even at 2,000 km.

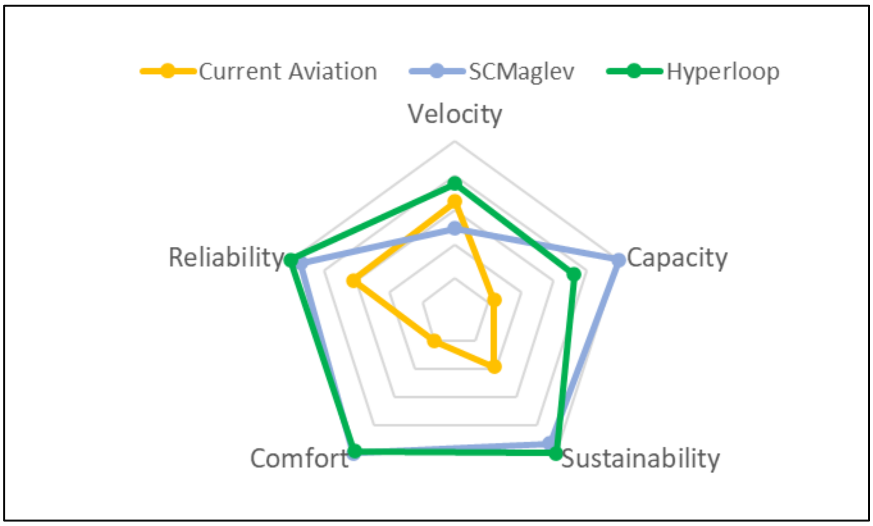


Figure 64. Aviation, superconducting maglev and hyperloop benchmark

Hyperloop's comfort, reliability, and sustainability can mimic or exceed those of HSR, UHSR or maglev (Figure 64). Speed can match that of airplane. In terms of capacity, which is frequently contested, it has two different answers; (1) from a business case standpoint, hyperloop capacity is enough, and there is room for improvement while technology develops, (2) hyperloop capacity can largely exceed that of other forms of rail. For the explanatory purposes, the most conservative hyperloop approach was selected, not meaning that the other approaches should be rejected.

10. Short-term and Long-term Research Vision

Since the release of the first hyperloop study (SpaceX & Tesla, 2013) in 2013, a remarkable and rapid evolution of the hyperloop technologies has been observed. The development of a hyperloop system attracted a lot of interest from private and public stakeholders, industrial leaders and R&D entities. However, the hyperloop development is in preliminary stages and improving the technology readiness level depends on establishing initiatives and collaborations, with both the private and public sector.

Regarding short term research, the vision for integration of hyperloop in the ground transport model is essential. In order to successfully realize a hyperloop system, there are certain focal points that can be identified: establishing a common framework for standardization, setting up the foundation for implementation, continuing R&D, knowledge sharing, investing in long test tracks, securing financing and determining the implementation network.

To achieve an interoperable system, the standardisation process of hyperloop requires a R&D framework to support the technological development with the goal of converging to a common hyperloop solution. The framework should support medium- and real-scale test-track developments, ensuring that safety levels and reduction of infrastructure complexity are met. The final goal is to achieve the needed scalability for long-distance routes in Europe and globally, for society to benefit from this innovative system.

10.1. Technology and patents

Rapid advances show that several concepts, trends and technologies have already been identified, as well as, multimillion investments have been announced by industry and governments. Technical barriers and concerns have been identified and significant efforts have been made for the development of the pods and tube infrastructure. Feasibility, safety and reliability of the hyperloop sub-systems are some of the aspects that contribute to the successful implementation of the system. Accounting for interdependencies and interactions between different systems and sub-systems is also necessary to study the problems and find solutions to several technical challenges.

Nevertheless, during the past few years, a significant amount of research and patent activity on several aspects of hyperloop sub-systems can be highlighted. In Figure 65, it can be observed that there is an increased tendency in patent filing on different hyperloop technologies and especially in the field of pneumatic tube and tunnel systems. By investigating the intellectual property mapping and identifying the common areas of research, the collaboration of different hyperloop promoters in research and testing can be enhanced (Gkoumas & Christou, 2020b). Observing also the patent trends facilitates the understanding of the related innovations and global leaders in hyperloop development (Lux Research, n.d.). Although various developers have made efforts to develop pods in small sub-scale tubes or full-scale in a short track (0.5 km), addressing key technologies such as propulsion, levitation, partially evacuated tubes, communication and operating requirements, advances the hyperloop through competition (AECOM, 2020).

Currently, the proposed solutions have not yet been tested in full-scale environment for long distances and high-speeds. Depending, also, on how developers evaluate the benefits and drawbacks of the various sub-systems, different approaches exist which include, but are not limited to the proposed propulsion and levitation system. The detailed investigation of available data, are certain fundamental factors for understanding the most promising technological options in combination with the multidisciplinary technical aspects, and specifying key research paths. These may lead to new knowledge, enabling the realization of the fastest means of transport ever made (Noland, 2021).

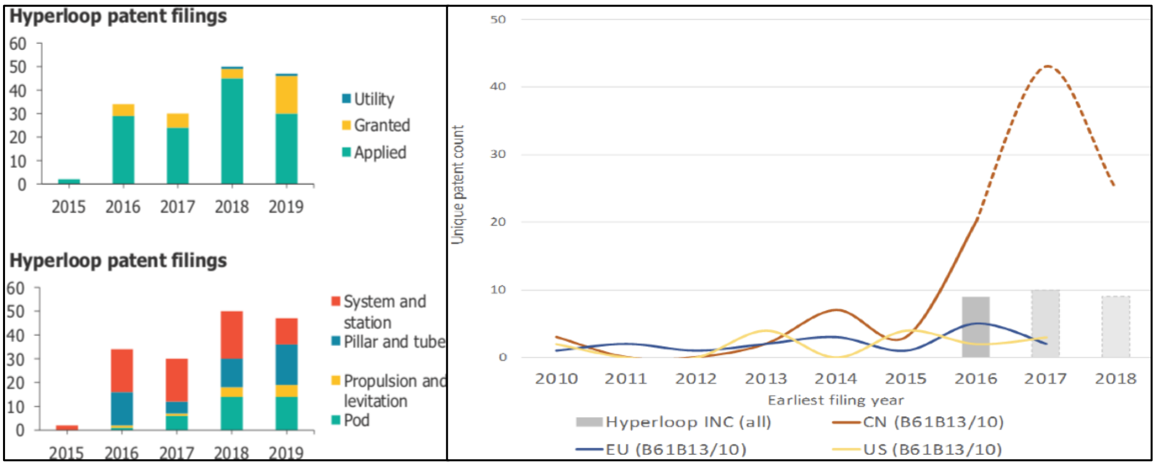


Figure 65. Hyperloop patent filings (left side) on various sub-systems (Lux Research, n.d.). **Patent application trends growth and patents filed under B61B13/10 (pneumatic tube and tunnel systems)** (Gkoumas & Christou, 2020b)

10.2. Gap identification, research vision and actions

Following, the needs of this section, a comprehensive gap analysis is introduced to identify research gaps, link them to research vision and propose research actions and directions towards reaching to successful implementation of the hyperloop system. The method of gap analysis is usually introduced in project management, comparing the actual performance with the potential one, improving at the same time business efficiency. A gap analysis is a systematic process that can broadly locate where the business is at present, determines the vision for the future and may also be expanded with a time scale. A quantitative analysis of the performance gap along with identification and understanding of the underlying causes for gap existence of business processes can lead to identification of opportunities for improvements, which constitutes the main target of gap analysis (Basu & Wright, 2005).

Furthermore, a number of other benefits can be reported (Basu & Wright, 2005), including but not limited to: the understanding of the total business process and the success factors, underpinning performance and best practices, as well as the general improvement in performance and practices, even before the start of the implementation plan. According to a recent study (Nolan & Anderson, 2015), a gap analysis can be implemented in six straightforward steps:

Step 1: Decide the topic of the gap analysis
Step 2: Identify the current status, based on metrics or attributes
Step 3: Identify the goals over a specific time frame
Step 4: Identify the gap between the current status and the envisaged goals
Step 5: Determine how the gap should be filled.

A methodology with a two-level gap analysis has recently been developed with respect to certain thematic areas, addressing the context of intermodal interconnections and identifying requirements and existing gaps between the transport industry and the educational community (Mitropoulos et al., 2017). At this study, data collection and analysis played a crucial role for the assessment of the present situation, as well as formulation of a plan of action to bridge identified gaps defining also deficiencies or requirements. Based on the methodology developed on the aforementioned study and the guidelines for a systematic literature review provided by Kitchenham (Kitchenham, 2004), a methodology for the implementation of hyperloop gap analysis is composed of:

1. Identification of the resources for hyperloop development
2. Study selection on a sub-system-based analysis, ensuring research is on a relevant topic and an appropriate quality.
3. Data analysis, extraction and synthesis of the information on relevant components in a short- and long-term base.
4. Identification of gaps between the current status of the hyperloop development and the envisaged goals.
5. Report writing; communication of results and dissemination in appropriate formats.

Data collection and analysis of the system components has been conducted by reviewing the recent literature on hyperloop development (AECOM, 2020; BAK Economics AG, 2020; Chesterton & Davies, 2018; Delft Hyperloop, 2019a; Gkoumas & Christou, 2020b; Kumar et al., 2018; Lux Research, n.d.; Noland, 2021; TNO, 2017; Walker, 2018). The current gap analysis has sought to demonstrate key technological gaps, by comparing the current state with the preferred short- and long-term goals, and at the same time to identify the requirements, by prioritizing possible actions and initiatives. The lack of concrete proof of functionality of a hyperloop system reaching subsonic or near-sonic speeds are highlighted and the outcomes of this analysis provide the directions to design refinements of the various sub-components.

The structure of the gap analysis follows the grouping that was followed in this report; thus, present findings for hyperloop components: infrastructure, pod, communication system, governance and performance impacts. Table 6 and Table 7 summarize findings for short- and long-term research vision, respectively.

Maturity of the technology has to be assessed and the deployment of a complete system requires multiple phases, from the construction of testing infrastructures to a robust commercially available system (Figure 66).

Testing Phase		Commercial Phase	
Development & Testing	Certification	First route	Network
3 - 15 km		Minimum of 40 km	>> 40 km

Figure 66. Track lengths during the different phases, from development to a full hyperloop network (TNO, 2017)

According to a recent study (TNO, 2017), a test track length at the range of 3 km to 15 km at full scale is required to implement the hyperloop development, testing and certification. At a length of at least 40 km, the full hyperloop system for passenger transport will be certified. The European Hyperloop Development center (Zeleros, 2021b), the European Hyperloop Center (HDP, 2021) and the EuroTube (EuroTube, 2021) are certain initiatives to accelerate the realization of the hyperloop vision. However, track facilities are intended to open in 2022 providing testing grounds, at a scale 1:2, and in 2026, EuroTube is planning to launch more than 30 km full scale test tracks for testing passengers and cargo pods (Figure 67).

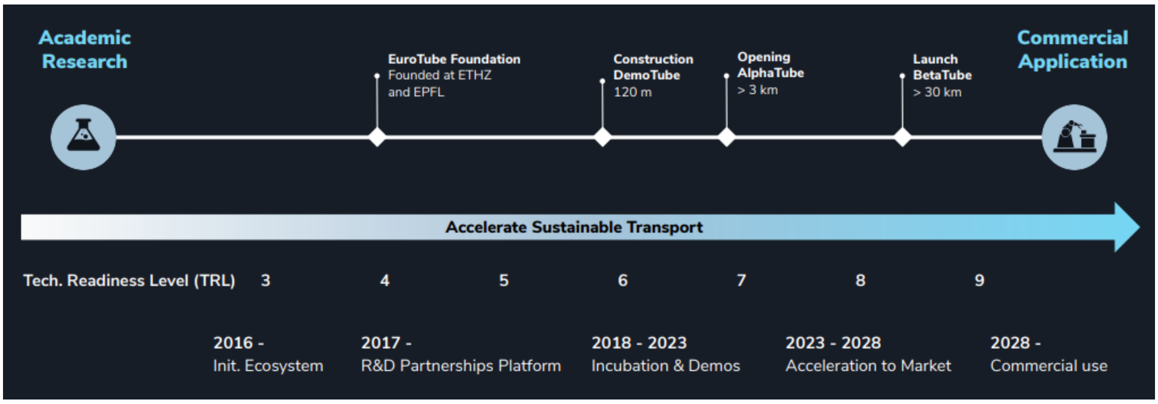


Figure 67. EuroTube's plan for construction of a full-scale testing facility and increasing the technology readiness level (Inauen & EuroTube, 2021)

Figure 68. Zeleros's overview of the European Hyperloop Development center testing facility proposed for Spain (Zeleros, 2021b)

Moreover, certain simulations are required to optimize further the sub-component design, such as the design of the tubes, the pylons, the systems for vacuum, levitation and propulsion and the pods. The reasoning for selecting the levitation and propulsion system shall be determined conducting simulations and be conformed to the requirements of a low-pressure-based environment. The various combinations between the tube’s operational energy consumption and the aerodynamic performance of the pod shall be simulated and evaluated in terms of optimal operating energy consumption, tube pressure and passenger pod capacity.

Additional demand related aspects, that need to be considered in the short term and ensure a smooth progress of the hyperloop system are the following:

- Establish a definitive demand forecasting approach/methodology for hyperloop, such that alternative schemes are analysed in a comparable and consistent manner. This approach would focus on the most important features of the journey experience (e.g., fares and journey times), be amenable to the analysis of competition with rail and air, and be readily tractable using available industry data at the European level.
- Undertake willingness-to-pay (WTP) research to better understand the key trade-offs, e.g., journey time vs. fares vs. comfort, inherent within the competitive environment for hyperloop. A particular focus would be to determine whether existing understanding of such trade-offs, e.g., such as the value of travel time savings, can be readily extrapolated to hyperloop, or whether there are idiosyncrasies of hyperloop that introduce new dimensions to such trade-offs.
- Following from the previous point, it could be instructive to undertake focused behavioural research, to better understand the perceived advantages (e.g., speed) and disadvantages (e.g., noise and comfort) of hyperloop from the passenger perspective.
- Depiction and identification of requirements for integration of new lines (whether traditional or Hyperloop) into existing transport networks, including competitiveness issues, and passenger flow prediction models.

The road to achieve scalability of hyperloop systems is long and complex, since the technology is not sufficiently mature. However, specifying short- and long-term goals and performing a gap analysis are conducive to the understanding of the various technical aspects and to overcome the challenges from the current phase, considered at the moment, impossible. The challenges may include unproven technologies, the absence of sufficient information and at some cases, of initial concepts. The feasibility and efficiency of several core technologies have not yet been evaluated and verified at the proposed speed range and the current progress from the various developers -seeking to gain a competitive advantage, is unclear. Therefore, creating a relatively straightforward approach, such as a gap analysis, aids to evaluate objectives, aspirations and actions at different timescales.

The next five years are critical to solve various technical issues, creating a robust and sustainable design. As expected of an emerging technology, various areas need of further research. Table 6 and Table 7 summarize those recommendations requiring further research and identify the areas, where feasibility shall be assessed. Until now, various developers have focused on the development and testing prototypes at a subscale level. However, ensuring a safe operation and creating proof of concept at real scale and high speeds are important considerations and never conducted before. In Europe, the plan of those shall be considered as a short-term goal. A long real scale test track will not only facilitate further testing and design refinements of the pods, tube operations, levitation-propulsion and communication systems, but also assist on the planning of regulatory considerations for a commercially available hyperloop. Regarding governance, an appropriate scheme for legislation, regulations, standards and guidelines shall be developed by enhancing at the same time R&D frameworks and initiatives and combining a dynamic participation of the public and private sector. Environmental considerations, planning requirements and constructions costs have also to be considered to envision a commercially viable hyperloop.

This gradual progress following a detailed roadmap, will lead to the need for further research. Once system components become available, new challenges and proposals for research will rise to institutions and researchers. A long-term research vision for tube transport, hyperloop, hyper tube and maglev will include also the identification of technical needs of common interest to academic, government, non-profit, and private sector.

Table 6. Short-term gap analysis for hyperloop system components

Component	Short-Term Goal	Current State	Identified Gap	Action Plan
Tube	• Tube design: definition tube diameter size, material and proof of concept for dimensional stability of the tube. • Perfect alignment of different tube segments. • Define the strategy for tube installation, transport, thermal joints and connections of different tube segments. • Define the number and characteristics of airlocks (equipped with gate valves) for fast and efficient boarding and disembarking of passengers.	• Various companies created smaller scale testing infrastructures. • Most companies have identified the technical requirements. • Maximum existing length for full-scale test track is: 500 m with 3.3 m diameter. • Tube design under study. Multiple sub-components have not yet been defined (i.e., materials, thermal joints, diameter size are still in design and test phase).	• Lack of testing facilities in real scale and bigger lengths. • The choice of the tube diameter is a trade-off solution between pod size, speed, power consumption and not yet defined. • Few initial studies available on the prediction of the infrastructure cost. • The choice of the tube material is a trade-off solution between stiffness, leakage, environmental impact and cost. Steel and/or reinforced concrete are certain predominant options, however limited design concepts are available.	• Simulations are required to optimize tube pressure and passenger-carrying capacity. • Tube prototypes to be tested for structural integrity, leakage rates and vehicle operations at low speeds and various scales, investigating new findings at a lower cost. • Longer full-scale test facilities should be created. • R&D studies to define the structural integrity using steel, reinforced concrete and/or composites. • Exact diameter and dimensional stability shall be verified by documentation and testing.

Component	Short-Term Goal	Current State	Identified Gap	Action Plan
			• There is a high risk of vacuum leakage due to the connection of different tube segments. No proven experimental studies available. • Limited studies on dimensional stability; tube and pod weights, vacuum pressure and thermal expansion can influence such a constraint.	
Pylons	• Finalize pylon design. • Identify infrastructure vibrations relative to the pylons' span. • Evaluate the guideway infrastructure.	• Pylons' geometry, size, material and spacing are under study. • Various companies created testing facilities at smaller scales and lengths.	• Long continuous tube structures may lead to a high dynamic amplification factor. Limited studies on investigating the structural performance of the pylons. • Small test track length exists, however full-scale testing is limited.	• Design and verification of the guideway infrastructure for various routes. • Longer full-scale test facilities shall be created. • Operational tests at full-scale and high speeds are required and the exact design shall be verified by documentation testing.
Airlocks	• Define the number and characteristics of airlocks (equipped with gate valves) for	• Concept of boarding and disembarking of passengers is still unclear.	• Components have not yet been verified and are untested.	• Develop a robust plan for boarding and disembarking.

Component	Short-Term Goal	Current State	Identified Gap	Action Plan
	fast and efficient boarding/disembarking of passengers. • Plan for maintenance and monitoring of the airlocks.	• Maintenance plan and monitoring technology have not yet been developed.	• Lack of passenger flow simulations and studies to define as well maintenance plan and monitoring technology.	• Documentation and testing of airlocks at real scale facilities, establishing ways for maintenance and monitoring.
Vacuum	• Maintain a low-pressure environment through a smaller segment and evaluate the depressurization time. • Define the spacing between the vacuum pumps, the number and location (to be housed in a separate building or attached to the tube exterior) • Define the energy consumption and cost of the initial pump-down. • Define the depressurization time of smaller segments. • Investigate possible failures of the vacuum pumps. • Identify the exact value(s) of pressure. • Verify system efficiency for vacuum pumps, valves and airlock chambers.	• The majority of the tests have been implemented on smaller scales and track lengths. • Only few hyperloop companies have tested vacuum pumps at full-scale. • Scaling and development issues have been addressed.	• Lack of a robust solution for full-scale and experimental demonstration for bigger track lengths. • No data available for energy consumption, costs and time of the initial pump-down operation. • Full documentation of possible failures is not available.	• Prototyping in operational environments and evaluate performance in bigger track lengths. • Conduct CFD simulations of the integrated tube-components. • Evaluate the initial pump-down operation in terms of energy consumption, cost and time. • Design verification via documentation and testing, defining the density of the vacuum pumps across the tube length.

Component	Short-Term Goal	Current State	Identified Gap	Action Plan
Propulsion	• Propulsion technology assessment based on power consumption, cost, reliability, safety and complexity. • Create a back-up propulsion system in case of power outage. • Create a final design and perform cost comparison studies, defining whether the propulsion components of high energy consumption are being placed inside the pods or along the various segments of the infrastructure. • Optimal design of the propulsion system to counter impacts occurring at ultra-high speeds. • Establish the maintenance requirements.	• Technologies tested at low speeds and small tube lengths, most of them at sub-scale testing facilities. • Only few hyperloop developers have tested propulsion technologies at full-scale, however at low speeds. • Hyperloop developers demonstrate competitive advantage using infrastructure-side propulsion technologies, as this has been proven at relatively high speeds in the existing Maglev systems.	• Technology not ready for implementing high speeds. • Full documentation of possible failures is not available. • Lack of a robust solution for full-scale and experimental demonstration for bigger track lengths. • No data available for energy consumption and costs.	• R&D studies for the energy efficiency, reliability and safety of the propulsion concepts. • Prototyping in operational environments and evaluate performance in longer tracks. • Establish experimental demonstrations of different concepts to evaluate performance and efficiency of the propulsion system at ultra-high speeds.
Levitation	• Establish a robust plan for the preferred magnetic levitation, to balance energy consumption, infrastructure costs and operation reliability.	• Maglev technologies already tested, however limited tests occurred in low-pressure environment and not on subsonic and transonic speed ranges. • Only few hyperloop developers have tested	• Technology not ready for implementation for high speeds and low-pressure environments. • Lack of a robust solution for full-scale and experimental	• Establish experimental demonstrations of different concepts to evaluate the levitation system for high-speeds. • Prototyping in operational environments and

Component	Short-Term Goal	Current State	Identified Gap	Action Plan
		levitation technologies at full-scale, however at low speeds.	demonstration for bigger track lengths. • Full documentation of possible failures is not available.	performance evaluation in bigger track lengths.
Pod	*Interior:* • Passenger comfort to be satisfied based on the accelerations of the pod in curves and switches. • Optimal seating arrangement to enhance safety. • Impact assessment of noise for passengers travelling in the pods. *Structure:* • Design of a lightweight pod with a reduced aerodynamic drag and various. • Design cargo pods as dedicated systems or interchangeable units. • Ensure regular pod maintenance and monitoring. • Design appropriate door seals to prevent pressure imbalances.	*Interior:* • Conceptual designs have been implemented. *Structure:* • Various companies demonstrated pod design.	*Interior:* • Not proven interior design feasibility. • Only few concepts for interior design have been implemented. *Structure:* • Details on the materials and performance are not demonstrated. • Concepts are described in a general way and no adequate information and studies are available. • Feasibility and costs studies have not yet been implemented.	*Interior:* • Study pod comfort by simulating multiple aspects, including seat comfort, thermal comfort, crowdedness, psychological distress, noise, motion sickness and access to facilities. *Structure:* • R&D to define an optimized aerodynamic pod, capable to reach the anticipated ultra-high speeds. • Prototyping in operational environments and evaluate performance via documentation and testing.
Governance	• At European level, standardization of the system components is required to enhance the	• In Europe, initiatives for hyperloop standardization already exist (CEN/CLC/JTC	• In Europe, standardization, legislation and policies	• Enhance the R&D framework with a combined dynamic

Component	Short-Term Goal	Current State	Identified Gap	Action Plan
	hyperloop development, including technical requirements such as tube size, operating pressure and speeds, guideway layout and pod size. • Legislation and policies are required to enable safe integration into the existing transport infrastructure.	20 - Hyperloop systems, Hyperloop Development Program, European Hyperloop Development Initiative). • The US Department of Transportation (USDOT) has released a status report on hyperloop standard development.	development are at a very early stage and are considered as preliminary studies.	participation of the public and private sector. • Increase funding from industrial partners and governments.
Communication	• Create a communication system capable to operate with high capacity and quality of services, creating an autonomous system at high speeds.	• Multiple radio systems and wireless mobility solutions have been tested in extreme conditions. Companies have announced collaborations (Icomera, 2021; Radwin, 2020) to implement a cutting-edge communications system for ultra-high-speed transport pods. • Advanced wireless technologies are being deployed in rail.	• Evaluation and tests occurred with various technologies; however limited data is available. • Communication efficiency and fast broadband speeds on an ultra-high transport system remain unknown. • Adaptation of the communication systems to hyperloop's very demanding constraints is not yet proven.	• Operational tests at real scale and high speeds are required. • Evaluation of the communication systems via documentation and testing.
Special alignment requirements	• Determine the changes that need to be addressed in the alignment	• Only a couple of research publications, refer to this aspect and attempt to	• Lack of a guidelines for addressing alignment aspects, such as	• Expand the current of practice for designing HSR and maglev rail alignments. Conduct

Component	Short-Term Goal	Current State	Identified Gap	Action Plan
	design of a hyperloop system traveling at sub-sonic speeds.	discuss potential changes in the tube alignment.	centrifugal forces at horizontal and vertical curvatures.	simulations and draft a hyperloop design guidelines for transportation engineers.

Table 7. Long-term gap analysis for hyperloop system components

Component	Long-Term Goal	Current State	Identified Gap	Action Plan
Tube	• Construction of a reliable and low-cost tube and its supporting structures. • Commercial operations to be planned when TRL 9 is achieved. • Minimize cost of tube construction and tunnelling. • Development of high-speed switches to realize point-to-point connections. • Develop maintenance and monitoring systems for the high-speed switches to ensure lateral guidance and safety on switching. • High-speed track-switching technology combined with small and frequent vehicles, to allow for on-demand travel.	• Structural integrity, vacuum leakage rates and vehicle operations have been tested at very low speeds. Only one company (Virgin Hyperloop One) has shown proof of concept at real scale on just 500 m of track. • Current developments on high-speed switches are in the early stages and the technological feasibility is yet to be proven. Existing switching systems are functional at very low speeds. The only hyperloop switching technology demonstrated publicly is the one developed by Hardt (conducted at low	• Increase of speed and testing facility size is required. • More than 40 km test tracks are required to get to the final TRL 9 for the full system (TNO, 2017), however currently only 500 m testing track is operational. • No known scaled version of a high-speed switch exists. • Implementation of high-speed switching with only electromagnetic components has not been proven at scale.	Longer full-scale testing facilities to be created and several aspects to be tested at scale: • Tube junctions with high-speed track switching. • Passenger-friendly airlock systems. • Emergency exits. • Noise impacts on neighbouring land use. • Thermal expansion over a long distance. • Station/portal systems. • System performance under high-speed operation. • Dimensional stability. • Functionality of magnetic-based switching system.

Component	Long-Term Goal	Current State	Identified Gap	Action Plan
		speeds and at a reduced scale).		
Vacuum	• Define maintenance requirements for infrastructure and tube. • Define maintenance and monitoring of the vacuum pump system to ensure a constant vacuum over long segments of the tube. • Establish the periodic operation plan to maintain the vacuum.	• Tests have been implemented on smaller scales and track lengths. • Several hyperloop companies have tested at full-scale. • Scaling and development issues have been addressed.	• The majority of companies have tested on a sub-scale environment. • No data available for maintenance and periodic operation plan.	• Operational tests at real scale and high speeds to be planned.
Propulsion	• Propulsion components connection to the high-power grid. • Verify the energy consumption of the system. • Performance evaluation using onboard batteries. • Create a system compatible with the proposed speeds.	• Immature propulsion technologies for the proposed high-speed range.	• Not proven technology on the hyperloop speed and vacuum requirements.	• Operational tests at real scale and high speeds to be planned.
Levitation	• Create an effective levitation system compatible to the proposed speeds.	• Maglev technologies already tested.	• Not proven technology on the hyperloop speed and vacuum requirements. • Lack of a robust solution for full-scale and experimental	• Operational tests at real scale and high speeds to be planned.

Component	Long-Term Goal	Current State	Identified Gap	Action Plan
			demonstration for bigger track lengths.	
Energy	• Establish a heat management plan to efficiently distribute and store the propulsion losses. • Evaluate energy consumption and levitation system compatibility. • Create the renewable energy plan to power the hyperloop. • Ensure safety and reliability of the systems at the targeted high speeds. • Build a lightweight and energy efficient on-board battery technology.	• Power system requirements remain uncertain. • Power delivery via renewable energy sources is under study. • Technologies tested at low speeds and small tube lengths, most of them at sub-scale testing facilities. • Some hyperloop developers have speculated that the entire network could be powered by solar energy or mix of renewable energy sources.	• No details have been provided and the feasibility to deliver power through renewable energy sources remains unknown. • Power transfer from the electrical grid to the vehicle or infrastructure remains unknown. • No heat management for propulsion losses has been established. • Heat management solutions have not yet been developed and due to the vacuum-based tubes, prediction of heat transfer is challenging. • Power transfer from electrical grid to vehicle is not readily available to satisfy both the speed and scale of Hyperloop.	• A comparative analysis of different proposals for the thermal management of the propulsion losses should be developed. • Evaluation of the energy consumption of sub-systems, via simulations, testing and documentation. • Feasibility analysis of renewable energy systems for different expected power system requirements and combinations.

11. Conclusions

Conclusions

Currently, the development of the core technologies is in progress. Developers shall focus an important part of their work on establishing the power system requirements. Establishing the technical requirements, creating a heat management plan and conducting feasibility analysis of evaluation of various concepts for power delivery are some of the important items to be addressed. The system functionality of certain technologies at a sub-scale level and low speeds has been proven. The compatibility of the various systems in subsonic and transonic speed ranges and real scale has to be tested. For the operational speeds of a hyperloop, feasibility of both EDS and EMS technologies still needs to be proven. The comparitive study points that the EMS demonstrates a better potential against the EDS due to its lower power consumption. Constant power supply is required for both systems, however the energy consumption using permanent magnets can be reduced significantly by developing a suitable Inductrack guideway.

Operational tests, documentation, collecting and analyzing testing data and evaluation of the cost of a potential commercially available system are factors to be considered for hyperloop.

Coming to the legal aspects, it is clear that establishing EU regulatory framework for hyperloop will be crucial to create a stable and predictable market, mobilizing public and private investments needed. Currently European legislation is divided into four main areas of application as far as transport is concerned: road, rail, sea and air. Hyperloop is an hybrid mode integrating subsystems from rail and aviation and thus requiring a specific regulation. However, the necessary decisions cannot be made, until the technologies are proven.

Investigating new findings at a sub-scale level will significantly lower the cost for the prototyping phase and may answer certain questions related to the implementation of a cost-efficient infrastructure, optimization of the pod design, as well as its capacity, and to ongoing assessments for the development of viable solutions for the core hyperloop technologies, such as levitation, propulsion and low-pressure/vacuum.

From an operational perspective, hyperloop is considered to have a good market potential in the case of routes spanning from 500 km onwards, with an optimum between 750 and 1,250 km, and remaining competitive even at 2,000 km. Hyperloop's strong points are reliability, sustainability and comfort (when compared to HSR) as well as speed, which is envisioned to be higher than that of commercial airplanes.

Key next steps to accelerate the development and deployment of hyperloop technologies includes among others:

- Establishment of a common framework for standardization, aiming to achieve, among others an interoperable system.
- Setting up the foundation for implementation of the hyperloop.
- Continuous Research and Development actions, coupled with knowledge sharing among different actors in Europe. The R&D framework should support medium- and real-scale test-track developments, ensuring that safety levels and reduction of infrastructure complexity are met.
- Investing in a long test track.
- Securing financing and determining the implementation network.

The final goal is to achieve the needed scalability for long-distance routes in Europe and globally, for society to benefit from a faster, cleaner and safer transport system. Existing research emphasizes the emerging role of identifying issues and challenges to better understand the parameters to create a robust, sustainable and cost-effective hyperloop design and show the links for a successful implementation and commercialization of hyperloop.

Since the first conception of hyperloop, a striking amount of research and patent activity on its sub-systems is widely-reported. Observing the patent trends, investigating the intellectual property mapping and understanding the interdependencies, interactions and complexity of the various hyperloop components are certain vitally important factors for a successful hyperloop development. Therefore, there is an urgent need to highlight the unique relationship between the various design goals and the maturity of technology over time. To that extent, a relatively straightforward approach, aiming to contribute to this growing area of research and to identify the potential gaps between the current state and the expected goals in different time scales, has been developed. A systematic literature review was conducted, data was analysed and evaluated, and the goals, impacting a successful realization of the hyperloop transportation system, were clearly indicated. The findings of the gap analysis will contribute to a deeper understanding of objectives, aspirations and actions, capable to bridge the identified gaps of the hyperloop development and lead to strengthen research in a more system-based and target-oriented approach.

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13. Appendices

Table A1. Non-EU stakeholders involved in hyperloop research and development.

Organization	Country	Continent
A. Santangelo Independent, Consulting Structural Engineer	US	N. America
AECOM	Canada	N. America
Bauman Moscow State Technical University	Russia	Asia
China University of Mining and Technology	China	Asia
Civil Engineering Dept BITS Pilani	India	Asia
College of Science and Engineering at Oral Roberts University	US	N. America
Department of Aeronautical Engineering Hindusthan Institute of Technology, Coimbatore, Tamilnadu	India	Asia
Department of Aerospace Engineering, Texas A&M University	US	N. America
Department of Civil and Environmental Engineering, Wonkwang University	S. Korea	Asia
Department of Civil Engineering, Yonsei University	S. Korea	Asia
Department of Electrical & Computer Engineering, Texas A&M University	US	N. America
Department of Electrical and Computer Engineering Ulsan National Institute of Science and Technology	S. Korea	Asia
Department of Electrical and Computer Engineering, University of Michigan-Dearborn, Dearborn	US	N. America
Department of Electrical Engineering, Hanyang University	S. Korea	Asia
Department of Industrial and Manufacturing Systems Engineering, University of Missouri Columbia	US	N. America
Department of Marketing, University of Missouri Columbia,	US	N. America
Department of Mechanical and Aerospace Engineering,Seoul National University	S. Korea	Asia
Department of Mechanical and Civil Engineering California Institute of Technology	US	N. America
Department of Mechanical Engineering, Andong National University,	S. Korea	Asia
Department of Mechanical Engineering, Chung-Ang University	S. Korea	Asia
Department of Mechanical Engineering, Guru Gobind Singh College of Engineering & Research Centre	India	Asia
Department of Railway Vehicle System Engineering, Korea National University of Transportation	S. Korea	Asia
Department of Transportation-John A Volpe National Transportation System Center	US	N. America
Departments of Mechanical Engineering, Chung-Ang University, Seoul	S. Korea	Asia
Electrical, Computer, and Software Engineering, University of Ontario Institute of Technology	Canada	N. America
High-Speed Railroad Systems Research Center, Korea Railroad Research Institute	S. Korea	Asia
Hyper Tube Express (HTX) Research Team, Korea Railroad Research Institute	S. Korea	Asia
HyperloopTT system	US	N. America
Institute of Advanced Aerospace Technology, Seoul National University	S. Korea	Asia
Korea Railroad Research Institute	S. Korea	Asia
Mechanical Engineering, Dept BITS Pilani	India	Asia
MIT hyperloop project	US	N. America
NASA Glenn Research Center, Cleveland, OH	US	N. America
New Transportation Innovative Research Center, Korea Railroad Research Institute	S. Korea	Asia
Northeast Ohio Areawide Coordinating Agency	US	N. America
Savitribai Phule Pune University	India	Asia
School of Architecture and Design, Southwest Jiaotong University, Chengdu	China	Asia

Organization	Country	Continent
School of Information Engineering, East China Jiao Tong University	China	Asia
School of Intelligent Energy and Industry, Chung-Ang University	China	Asia
School of Mechanical Engineering, Southwest Jiaotong University, Chengdu	China	Asia
School of Traffic & Transportation Engineering, Central South University	China	Asia
SpaceX	US	N. America
St. Petersburg State Transport University	Russia	Asia
State Key Laboratory of Aerodynamics, China Aerodynamics Research and Development Center	China	Asia
State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu	China	Asia
Tesla motors	US	N. America
The Pennsylvania State University	US	N. America
Traffic and Transportation, Beijing Jiaotong University, Beijing	China	Asia
TransPod Inc., Toronto, Ontario	Canada	N. America
University Higher School of Economics	Canada	N. America
University of Cincinnati, Cincinnati, Ohio	US	N. America
University of Toronto, Department of Electrical and Computer Engineering	Canada	N. America
US Department of Transportation	US	N. America
V.A. Trapeznikov Institute of Control Sciences	Russia	Asia
Worcester Polytechnic Institute	US	N. America

Table A2. Hyperloop publications in Asia

Source	Country	Type	Infrastructure	Pod	Performance	Comments
(Bansal & Kumar, 2019)	India	J	Tube	System/prop.	Other	Short review
(Ji et al., 2018)	Korea, South	J	Interface pod-tube		Other	Performance-thrust force
(Lim et al., 2020)	Korea, South	C	Interface pod-tube		Energy	Optimize on-board superconducting magnet with respect to cost and performance.
(Jiqiang et al., 2020)	China	J	Tube		Aerodynamics	Acceleration and deceleration
(Kaushal, 2020)	India	J				Review of hyperloop
(Harish et al., 2017)	India	J	Tube	System/prop.	Aerodynamics	Computational Fluid Dynamics (CFD) is used to simulate the air flow around the hyperloop pod in transonic speeds.
(Belova & Vulf, 2016)	Russia	C	Interface pod-tube		Energy	Analyze the pneumatic capsule for transport of different cargoes. Study pressure in real-time mode and movement of the capsule.
(Rob et al., 2019)	China	J	Tube	Both		Short review
(Dudnikov, 2019)	Russia	C	Station			Study the structure of the hyperloop passenger system when an intermediate station appears.

Source	Country	Type	Infrastructure	Pod	Performance	Comments
(Dudnikov, 2018)	Russia	C		Interior	Safety	Estimated time for the expiration of air from the capsule in an emergency situation.
(K. K. Kim, 2018)	Russia	C	Interface pod-tube		Aerodynamics	Alternative pipe design without using the technical vacuum but using the rarefied air in the pipe and the drive linear induction motor.
(S. Y. Choi et al., 2019)	Korea, South	J	Interface pod-tube	System/prop.	Energy	Introduced optimal design methods for linear synchronous motors and inverters, with design guidelines and examples for the commercialization version of the hyperloop.
(Dudnikov, 2017)	Russia	C	Tube	System/prop.	Other	Passenger and cargo transport. Capacity, costs, independence from weather conditions, ecological cleanliness and security.
(Oh et al., 2019)	Korea, South	J	Interface pod-tube	System/prop.	Aerodynamics	Investigated the flow phenomena of a hyperloop system.
(Le et al., 2020)	Korea, South	J	Interface pod-tube	System/prop.	Aerodynamics	Investigate effects of pod speed, blockage ratio (BR), tube pressure, and pod length on the drag and drag coefficient of a hyperloop,
(Pradhan & Katyayan, 2018)	India	C	Interface pod-tube	System/prop.	Aerodynamics	Braking forces
(Shinde et al., 2017)	India	J	Other	System/prop.	Aerodynamics	Short literature Tube, interface, propulsion, capsule-pod
(D. W. Kim et al., 2017)	Korea, South	J	Tube			Computational Fluid Dynamics to investigate this shock train phenomenon inside the shock tube.
(Seo et al., 2020)	Korea, South	J	Interface pod-tube		Aerodynamics	Study of magnetic levitation driving system of Hyperloop; performance analysis by analyzing the design requirements.
(T. K. Kim et al., 2011)	Korea, South	J	Tube		Aerodynamics	Study various parameters of the tube train system: internal tube pressure, blockage ratio, and operating speed through computational analysis with a symmetric and elongated vehicle.
(Zhou et al., 2021)	China	J	Tube		Aerodynamics	Simulate the motion in the tube by the dynamic mesh method; the evacuated tube maglev train studied under different suspension gaps.
(Zhou & Zhang, 2020)	China	J	Tube		Aerodynamics	High-speed movement process of evacuated tube maglev train was reproduced by numerical simulation.
(Sui et al., 2020)	China	J	Tube		Aerodynamics	Unstable aerothermal phenomenon, causing the temperature to rise sharply inside the tube and endangering the safe operation of trains and equipment.
(J. Choi et al., 2016)	Korea, South	J	Tube		Safety	Air flow through cracks.
(Jiqiang et al., 2020)	China	J	Tube		Aerodynamics	Study the differences in aerodynamic effects when the train accelerates

Source	Country	Type	Infrastructure	Pod	Performance	Comments
						(decelerates) past the speed of sound, and the influence of different values of acceleration (deceleration) on the aerodynamic effects.
(Sui et al., 2021)	China	J	Tube		Aerodynamics	Study the influence of the vacuum degree on the flow field around a train capsule running in an evacuated tube with circular section.
(Niu et al., 2019)	China	J	Tube	System/prop.	Aerodynamics	Formation and evolution mechanism of aerodynamic heating in the tube and influence of the Mach number at subsonic, transonic, and supersonic speed.
(Zhou et al., 2019)	China	J	Tube		Aerodynamics	Simulate the real motion of evacuated tube maglev train and improve the capture accuracy of the waves.
(Kwon et al., 2017)	Korea, South	J	Tube		Energy	Six different photovoltaic configuration cases.
(Tang et al., 2013)	China	J	Tube		Aerodynamics	Study of model parameters impacting train speed and the aerodynamic drag under multifield coupling.

Note: Journal (J), Report (R), Conference (C).

Table A3. Hyperloop publications in North America

Source	Country	Type	Infrastructure	Pod	Performance	Comments
(Rajendran & Harper, 2020)	United States of America	J	Other		Traffic	Simulation model San Fracisco-Los Angeles
(Decker et al., 2017)	United States of America	C	Other	System/prop.	Other	Pod: drag, cycle, drivetrain, geometry and mass, levitation. Tube: Vacuum, thermal management, propulsion, substructure.
(HyperloopTT, 2019)	United States of America	R	Other	System/prop.	Other	Performance: economic analysis, market, operating cost Tube, pod, vacuum system, station, route
(Santangelo, 2018)	United States of America	J	Substructure			Structural approach and design. Curves, materials, dynamics.
(Covel, 2017)	United States of America	R	Other	Both	Other	Economic analysis. Review all parts of infrastructure. Concerns and risks are outlined. Speed, time, energy, emissions, costs
(Opgenoord & Caplan, 2018)	United States of America	C		System/prop.	Aerodynamics	Aerodynamic design considerations for the hyperloop pod (aerodynamic design considerations for the pod).
(Sayeed et al., 2018)	Canada	C	Interface pod-tube		Energy	A comprehensive finite-element analysis to determine the design specifications of the pod levitation and propulsion control.

Source	Country	Type	Infrastructure	Pod	Performance	Comments
(SpaceX & Tesla, 2013)	United States of America	R	Other	Both	Safety	All aspects of infrastructure and pod. Route optimization. Safety, cost, reliability.
(Taylor et al., 2016)	United States of America	R	Station	Both	Other	Hyperloop Comparisons to Other Modes: Travel time, frequency, user cost, comfort, reliability, energy consumption, capacity, system resilience, system interoperability, costs, safety.
(Heaton, 2017)	United States of America	C	Substructure		Safety	Earthquake motions can cause lateral deformations of the tube that cause centripetal forces in the pod.
(Chaidez et al., 2019)	United States of America	J	Interface pod-tube		Energy	Power requirements for each of the three major modes of Hyperloop operation: rolling wheels, sliding air bearings, and levitating magnetic suspension systems.
(Nikolaev et al., 2018)	Canada	C	Interface pod-tube	System/prop.	Safety	Validate correctness of pod's software and embedded systems. Complete control of the pod throughout the launch.
(Sayeed et al., 2018)	Canada	C	Interface pod-tube	System/prop.	Energy	Finite element analysis on the effects of the magnetic field distribution. Effects of the magnetic field force.
(Halsmer et al., 2017)	United States of America	C	Interface pod-tube	System/prop.	Other	Develop a prototype for a high-speed, magnetically-levitated transport pod for the hyperloop competition.
(Soni et al., 2019)	United States of America	R	Interface pod-tube			Braking forces
(MIT Hyperloop Team, 2017)	United States of America	R	Interface pod-tube	System/prop.	Other	Aerodynamics, energy, vibration, software.
(AECOM, 2020)	Canada	R	Other	System/prop.	Other	Tube, tube switching, substructure, vacuum and power, propulsion and power. Energy, security, pod design, capital and operating costs. Risk assessment
(NETT Council, 2021)	United States of America	R				A literature review to identify domestic and international standardization activities being conducted by government entities, standards development organizations (SDOs), and private industry.
(Chin et al., 2015)	United States of America	J	Interface pod-tube		Aerodynamics	Aerodynamic and thermodynamic interactions between the two largest systems: thetube and the pod.
(Sirohiwala et al., 2007)	United States of America	R	Other		Other	Maglev, high speed, cost, safety, energy, aerodynamic.

Source	Country	Type	Infrastructure	Pod	Performance	Comments
(Janzen, 2017)	Canada	C	Tube		Aerodynamics	Aerodynamics, dynamics, vibration of tube.

Note: Journal (J), Report (R), Conference (C).

Hyperloop competing teams

Teams advancing to the prototype hardware build stage for 2016 include representatives from four continents and at least six countries. The selected teams include:

- AZLoop, Arizona State University, Embry–Riddle Aeronautical University, and Northern Arizona University
- Hyperloop Poland University of Wroclaw and University of Warsaw
- Badgerloop, University of Wisconsin–Madison
- Bayou Bengals, Louisiana State University
- Berkeley Hyperloop, University of California, Berkeley
- Carnegie Mellon Hyperloop, air-bearing subsystem Carnegie Mellon University
- Codex, pod design uses magnetic levitation suspension; team has only eight members as of February 2016. Oral Roberts University
- Delft Hyperloop, Delft University of Technology
- Drexel Hyperloop, building a design with air-bearing suspension and a compression braking using built-up air pressure in the Hypertube. Team is approximately 80 undergraduate students. Drexel University
- Gatorloop, pod design uses wheel suspension. University of Florida
- HyperBears, Baylor University
- HyperLift, St. John's School (Texas) The only high school team in the competition.
- Hyperloop UC, pod design used magnetic levitation, and was the first to demonstrate such technology.University of Cincinnati
- Hyperloop Toronto,University of Toronto
- Hyperloop at Virginia Tech V-17, Virginia Tech
- HyperXite, University of California Irvine
- Illini Hyperloop, has a history of previous Hyperloop design projects in the Mechanical Science and Engineering program, the first dating to the fall term of 2013. In addition to four subsystem design teams, the Illini group has a fifth, cross-disciplinary team focusing on safety and reliability, the prevention of branching failures. University of Illinois at Urbana-Champaign
- Keio Alpha, Micro-pod architecture consist of active and passive magnetic levitation suspension with a passive eddy current brake. It should weigh less than 45 kg and does not need to carry dummy passenger. Keio University
- Lehigh Hyperloop, Lehigh University

- Hyperloop Makers UPV team Valencia, Spain, won Top Design Overall award and Best Propulsion system awards in the first hyperloop competition. Always on the Top 10 globally participating in all hyperloop competitions.Initial proposal: Magnetic levitation based on attraction to the top of the tube. Rail-free and clean tube layout, compensation of inertial forces, reduced air-evacuation cost and up to 30% savings in infrastructure. Powered by detachable batteries, propulsion through compression and expansion of air with a nozzle. The concepts expanded with physical prototypes of vehicles proving levitation and propulsion capabilities and testing facilities built like low pressure tube facilities and rails at the Universitat Politècnica de Valencia.
- Mercury Three, University of Wisconsin, Milwaukee
- MIT Hyperloop Team, magnetic levitation suspension and high speed are the design focal points. no compressor for this test pod. Massachusetts Institute of Technology
- NYU Hyperloop, *Slate*, a freight-only pod, will use air-bearing suspension; is being designed and built by a team of, as of February 2016, fewer than ten undergraduate students. New York University
- OpenLoop, pod design will use an air-bearing suspension and compressor similar to the original 2013 Hyperloop alpha design. multi-university team of Cornell University (suspension), Harvey Mudd College (control systems), University of Michigan (fuselage), Northeastern University (suspension), Memorial University of Newfoundland (compressed air), and Princeton University (electrical and cooling)
- Purdue Hyperloop, Purdue University
- rLoop, Inc., The only non-student team that advanced in the competition and won the "Innovation Award." Initially conceived on a Reddit forum, rLoop is now a full-fledged, funded Hyperloop initiative with activity in over 14 countries.
- TAMU Aerospace Hyperloop, Texas A&M
- Team Frigates, Shiv Nadar University, Undergraduate design team consisting of 8 students from different disciplines, namely Mechanical, Physics and Electronics and Communications.
- Team HyperLynx, pod design uses high-speed wheel suspension, with a modular/removable payload design for a pod with a total mass of 140 kg (300 lb), aiming for a top speed of 400 km/h (250 mph). University of Colorado-Denver
- UCSB Hyperloop, pod design will use magnetic levitation suspension. Test runs will be accelerated by the Hypertube pusher. Undergraduate design team (senior project) of 20 members. University of California-Santa Barbara
- UMD Loop, University of Maryland
- USC Hyperloop, University of Southern California[1]
- UWashington Hyperloop, University of Washington
- Waterloop, a Canadian team designing a pod with air levitation, magnetic brakes and control, targeted at 250 kg (550 lb) aiming for a cruising velocity of 120 m/s (430 km/h; 270 mph) while carrying a payload of 4,000 kg (8,800 lb). University of Waterloo
- VicHyper, Royal Melbourne Institute of Technology

- WARR Hyperloop, pod design will use an electrodynamic suspension system to levitate and an axial compressor to minimize aerodynamic drag from the residual air inside the tube when the pod is moving at high velocity.
- Technical University of Munich
- HyperPodX, a German team with a pod designed to levitate using a series of fixed magnets following a Halbach array and a pusher with 4 electric motors for acceleration to high velocities The team is comprised from the conjoined effort from Engineering Physics students from the University of Oldenburg and the Hochschule Emden/Leer(de).