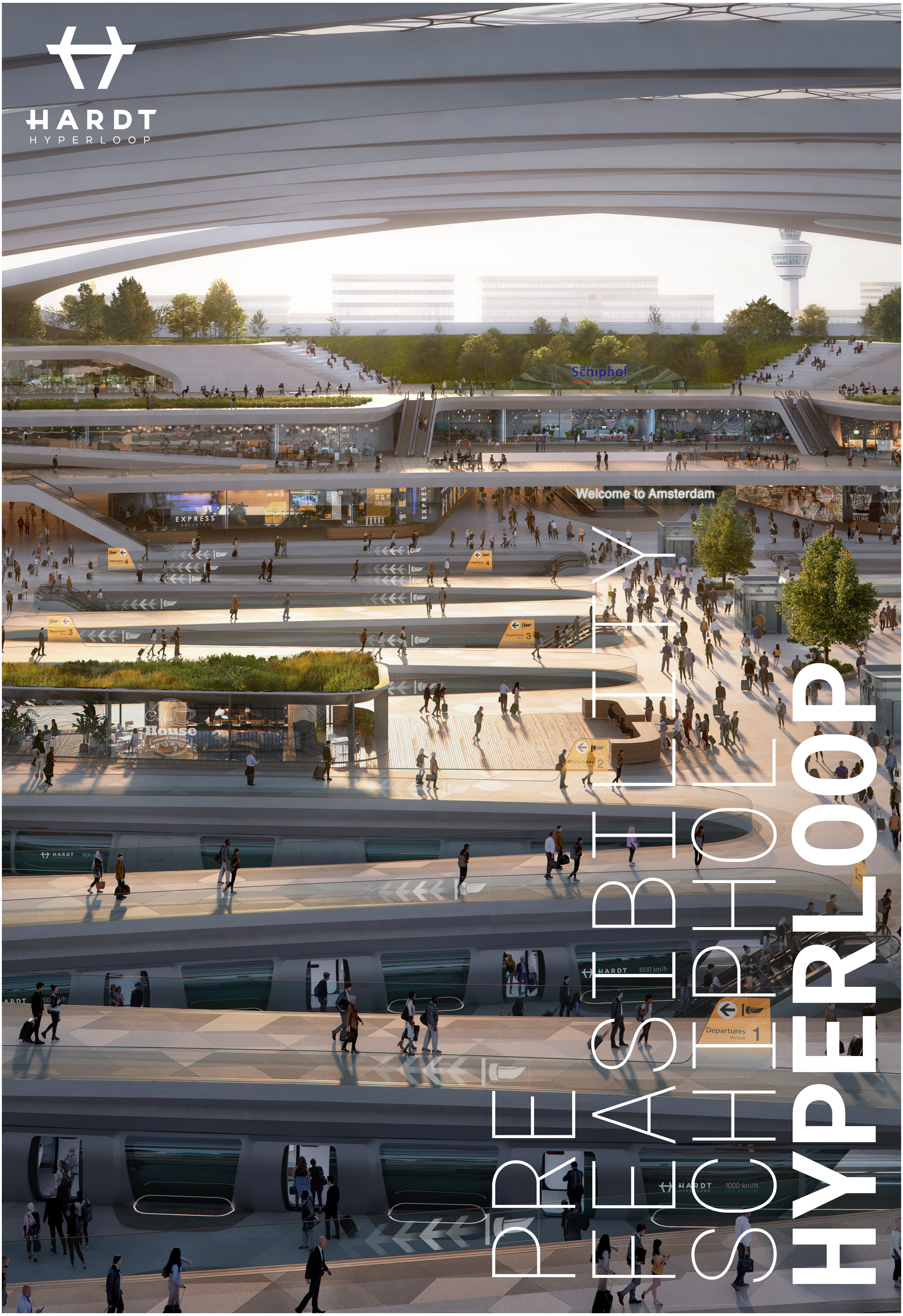
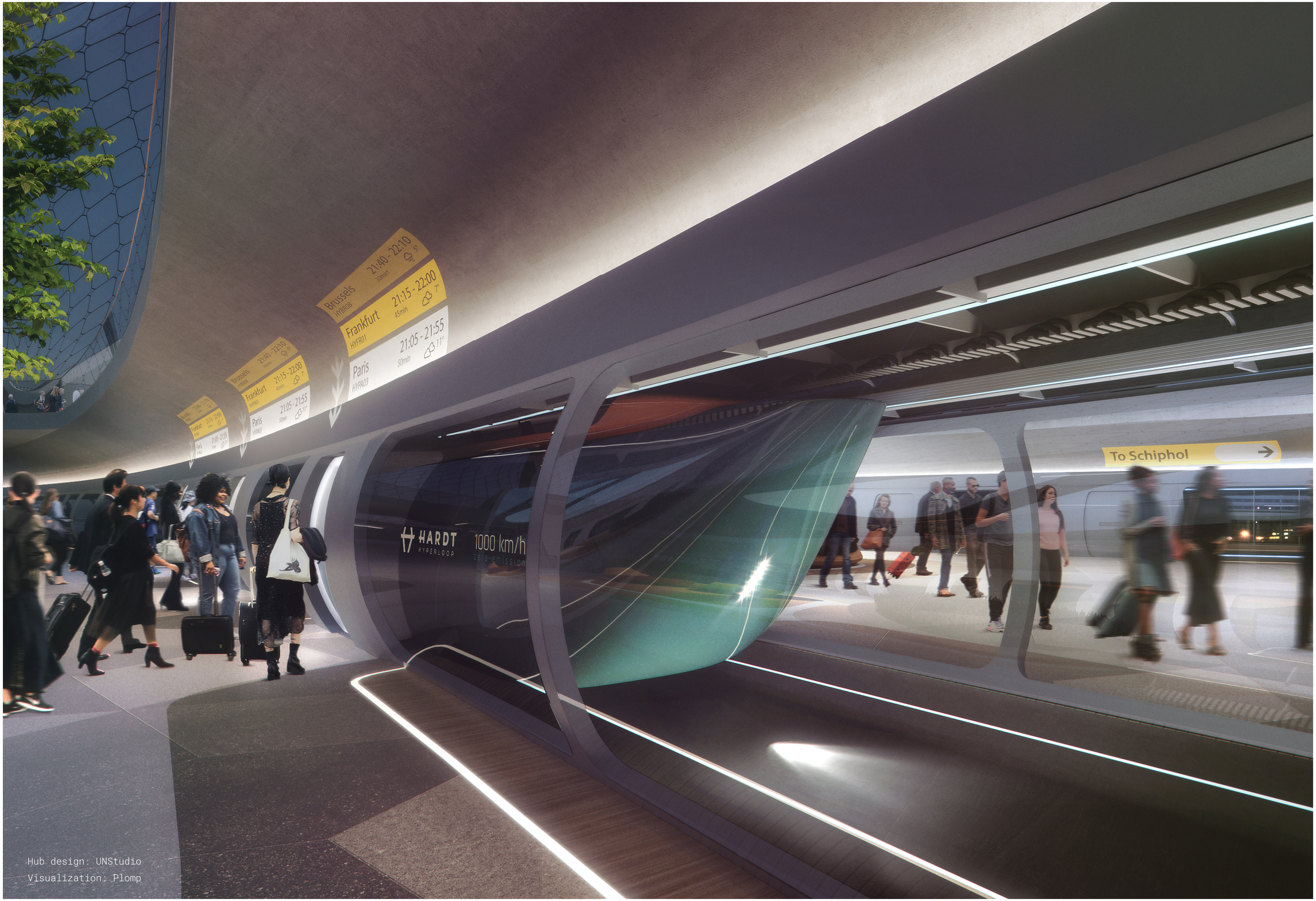
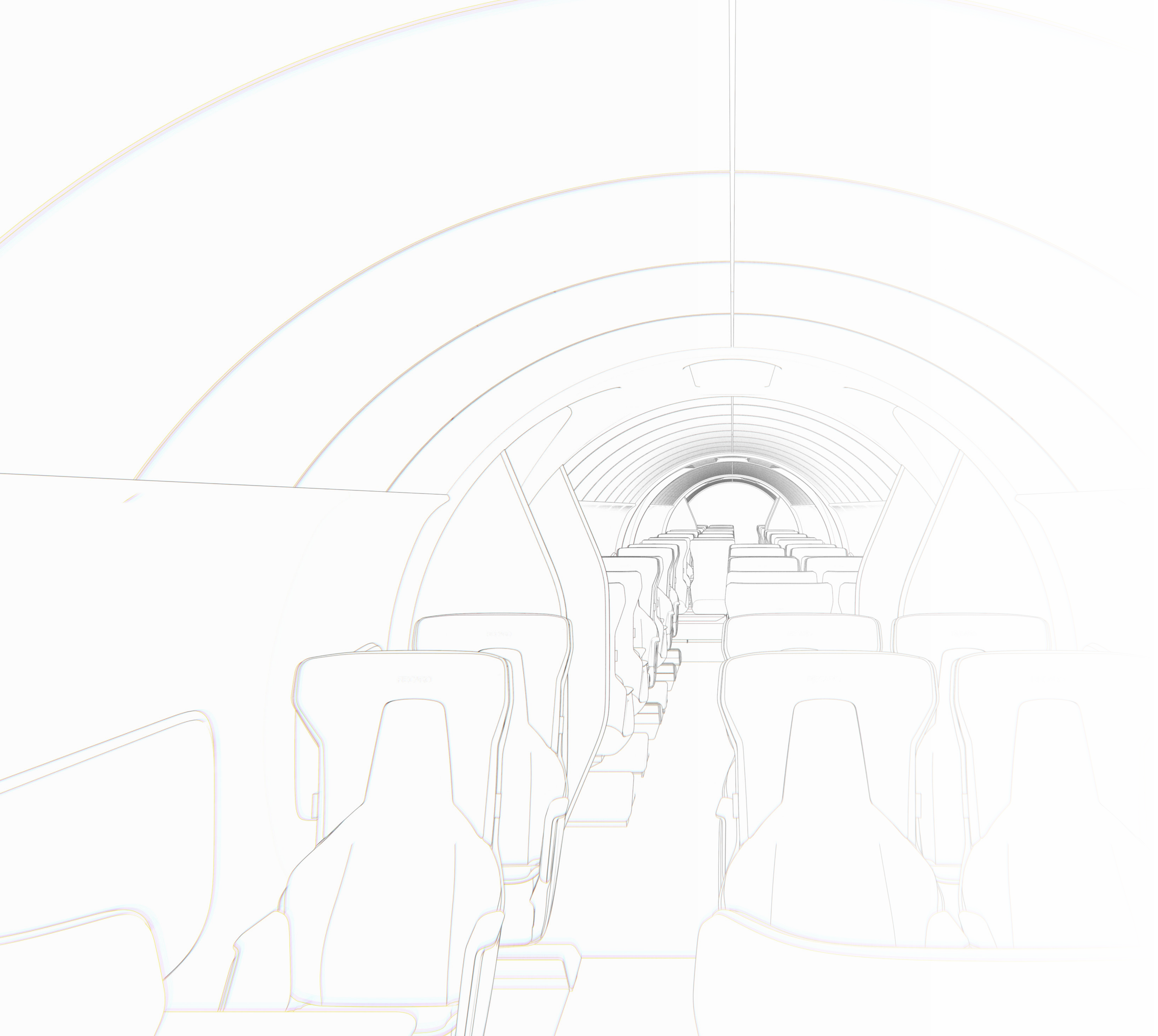
HARDT HYPERLOOP

PRE FEASIBILITY SCHIPHOL HYPERLOOP




Brussels
21:40 - 22:10
Frankfurt
HYFR01
21:15 - 22:00
45min
Paris
21:05 - 21:55
50min
HARDT
HYPERLOOP
1000 km/h
To Schiphol
Hub design: UNStudio
Visualization: Plomp



TOC

THE FUTURE OF ULTRA FAST CONNECTIONS TO AND FROM SCHIPHOL AIRPORT: THE HYPERLOOP

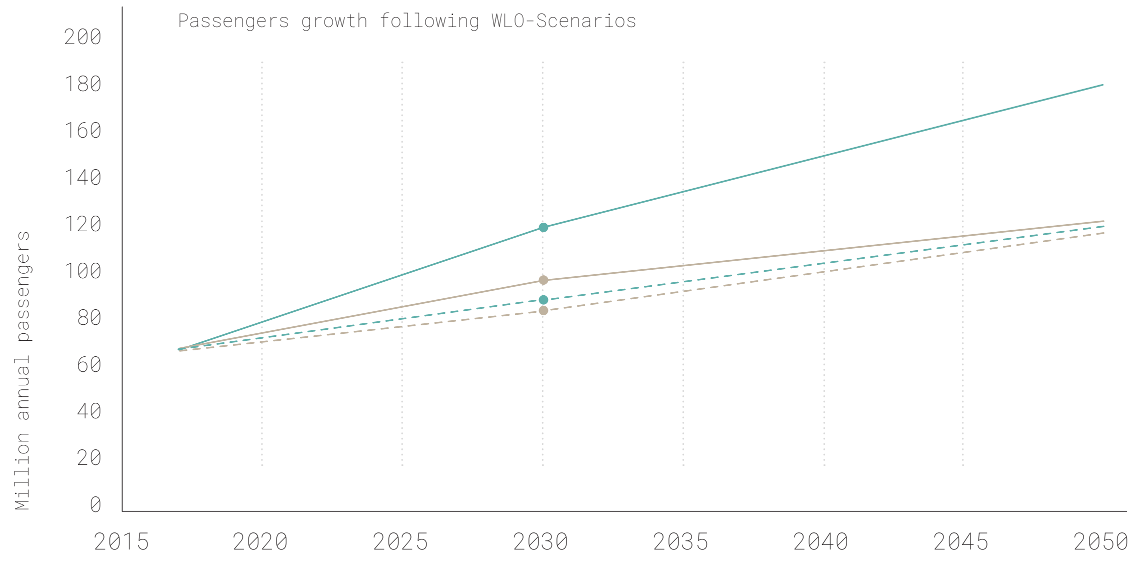
Royal Schiphol Group's partnership work is constantly evolving as it collaborates with various organisations to explore new forms of mobility, innovative transportation networks and other developments within the mobility landscape. As part of this, Schiphol and Hardt started their partnership. Announced in September 2018 during the HyperSummit, the partnership sees Schiphol working with Hardt to investigate to what extent can the hyperloop help us meet our future accessibility needs.

The hyperloop concept aligns closely with Schiphol's wider innovation programme and could prove to be a valuable addition to the future transportation landscape. In particular, this technology has the potential to become a successful mode of sustainable transport in the years ahead.

This booklet presents the results of a preliminary study. The research is based on the premise that Schiphol maintains its operations at the existing location, with the hyperloop functioning as a sustainable means of transport within a balanced vision for the development of Schiphol Airport as a whole.

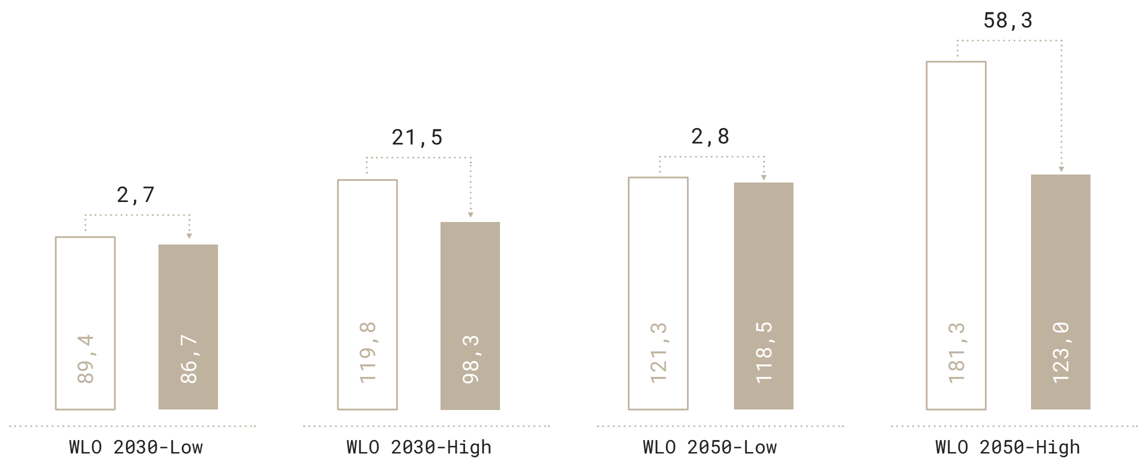
Our sincere gratitude to Royal Schiphol Group for their active and enthusiastic participation in the study. Happy Reading.

Hardt Hyperloop.



Unrestricted - High *Restricted - High* *Unrestricted - Low* *Restricted - Low*

Figure 1. Passenger growth forecast following WLO-Scenarios



Unrestricted demand *Demand accommodated*

Figure 2. Gap of passenger demand (in red, million passengers) at AAS in restricted scenarios compared to the unrestricted demand scenario in 2030 and 2050

INTRODUCTION TO SCHIPHOL AND THE PROJECT

Amsterdam Airport Schiphol (AAS) is vital to the Dutch economy. The airport enables The Netherlands to fulfill an important international function as a hub for trade and services. The further improvement of international accessibility, for both people and goods, is crucial to facilitating and strengthening the national economy. However, though accessibility and connectivity are of vital importance, the airport faces increasing pressure on its capacity; which creates challenges in facilitating the high network quality of the airport.

This study takes as its context the years between 2030 and 2050. During that period, following the WLO-Scenarios[1], aviation passenger demand is projected to grow at a higher rate than the airport can accommodate[2]. The WLO-scenarios set out two perspectives on passenger demand. The "unrestricted" scenario (in which no policy or capacity restrictions at the airport are considered), and the "restricted" scenario (where airport restrictions are taken into consideration). In the Restricted-High scenario, there is a demand gap in 2030 of 21.5 million passengers and in 2050 the gap increases to 58.3 million passengers compared with the unrestricted scenario. See figures 1 and 2.

A thriving aviation sector is essential to The Netherlands: it is crucial to supporting Dutch businesses and wider economic development. To ensure Schiphol maintains its strong position, alternative solutions need to be researched to sustainably accommodate future passenger growth.

Several potential solutions to deal with the constrained airport capacity focus on the substitution of short-haul flights. Recent studies into high-speed rail, proposing it as an existing alternative, show it has been unable to solve the problem[3]. All around the world infrastructure projects are running into problems, such as cost overruns and unexpectedly long lead times, resulting in increasingly congested cities. An estimated €1.500 billion needs to be invested in comprehensive European transport infrastructure within the next decade[4]. In selecting the projects for these investments, short-term congestion relief needs to be carefully weighed against the long-term sustainable opportunities that new solutions could bring, as the consequences of these investments will last a lifetime.

This opens the case for alternatives. Emerging innovations and new modes of transportation represent important opportunities for Schiphol. One of these is the hyperloop. A new type of ground-transportation, hyperloop is based on travel through a low-pressure tube where speeds similar to those in aviation can be achieved.

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[1] The study 'Nederland in 2030-2050: twee referentiescenario's – Toekomstverkenning Welvaart en Leefomgeving', or WLO for short, is the basis for many policy decisions in the field of the physical living environment in the Netherlands. The WLO was drawn up by PBL and CPB.

[2] Report: "Actualisatie AEOLUS 2018 en geactualiseerde luchtvaartprognoses, 15-02-2019, by Significance".

[3] Report European Court of Auditors: Report No 12 of 2018. A European high-speed rail network: not a reality but an ineffective patchwork: https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=46398w

[4] European Commission. 2018. Streamlining measures for advancing in the realization of the T-ENT network. P2.

http://www.europarl.europa.eu/RegData/docs_autres_institutions/commission_europeenne/com/2018/0277/COM_COM(2018)0277_EN.pdf

WHAT IS HYPERLOOP AND HOW DOES IT WORK?

The hyperloop is a new mode of transportation for large volumes of passengers and cargo. The infrastructure consists of tubes that can be built both above and below ground. Vehicles that resemble small aircraft travel inside the tube, either separately or in short trains of coupled vehicles. See figure 4 (Overview of the Hardt hyperloop system).

The hyperloop system is a combination of existing technologies from different industries which together form a new mobility concept. Where rail technologies use wheels on tracks, the hyperloop system uses magnetic forces for levitation, guidance and propulsion.

Air resistance and noise emission can both be major impediments at increased speeds. The hyperloop system counters these by operating with pressurised vehicles inside a low-pressure tube. The low-pressure environment reduces both air resistance and energy consumption, propelling vehicles to speeds of up to 1000km/h. The body of the tube lowers noise emissions towards the direct environment.

The hyperloop linear infrastructure comprises two parallel tubes that are either elevated on columns above the ground, run at ground level, or go underground. The two tubes allow vehicles to travel in opposite directions. In contrast to typical rail services, hyperloop travel runs directly between any origin and destination on the network without any intervening stops.

The hyperloop has the following key characteristics:

High capacity - up to 20.000 passengers per hour per direction at 700 km/h (or 40.000 passengers per hour with trains of coupled vehicles).

High transit speeds - operational speeds ranging from 500km/h to 1000km/h.

Low energy consumption - 38 Wh/passenger/kilometre at 700 km/h.

Low maintenance - magnetic levitation and propulsion without friction, and switching without moving components minimises wear and tear.

Zero operational emissions - fully electric, powered by renewable energy sources, produces zero operational emissions.

Minimised infrastructure footprint - the small footprint of the elevated infrastructure allows the hyperloop to follow existing infrastructure and reach, as well as integrate with transport hubs.

The sweet spot of hyperloop
The graph below presents the expected market share of hyperloop for 406 O-D pairs in Europe in short, medium, and long distances, compared to high-speed rail and aviation. It can be divided into three ranges:

100-500 km: in this range high-speed rail currently competes with aviation. Hyperloop could substitute a share of both HSR and aviation.

500-1750 km: substitution of flights in distances between 500 km and 1500 solely by hyperloop, as high-speed rail is not considered competitive, and hyperloop outperforms aviation in this range.

1750-3000 km: competition between aviation and hyperloop will occur as hyperloop proves to be competitive to aviation (similar to HSR and aviation in the range to 500km).

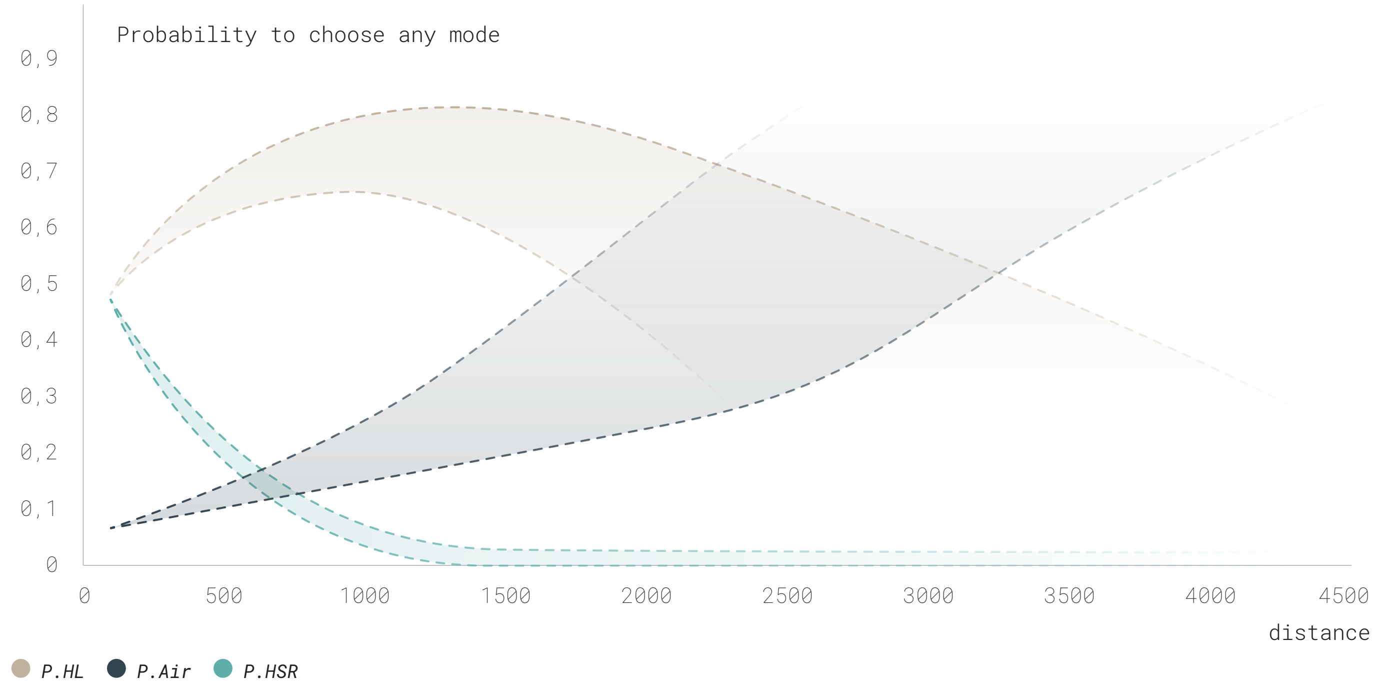


Figure 3. Probabilities to choose any mode modelled for 406 routes in Europe.

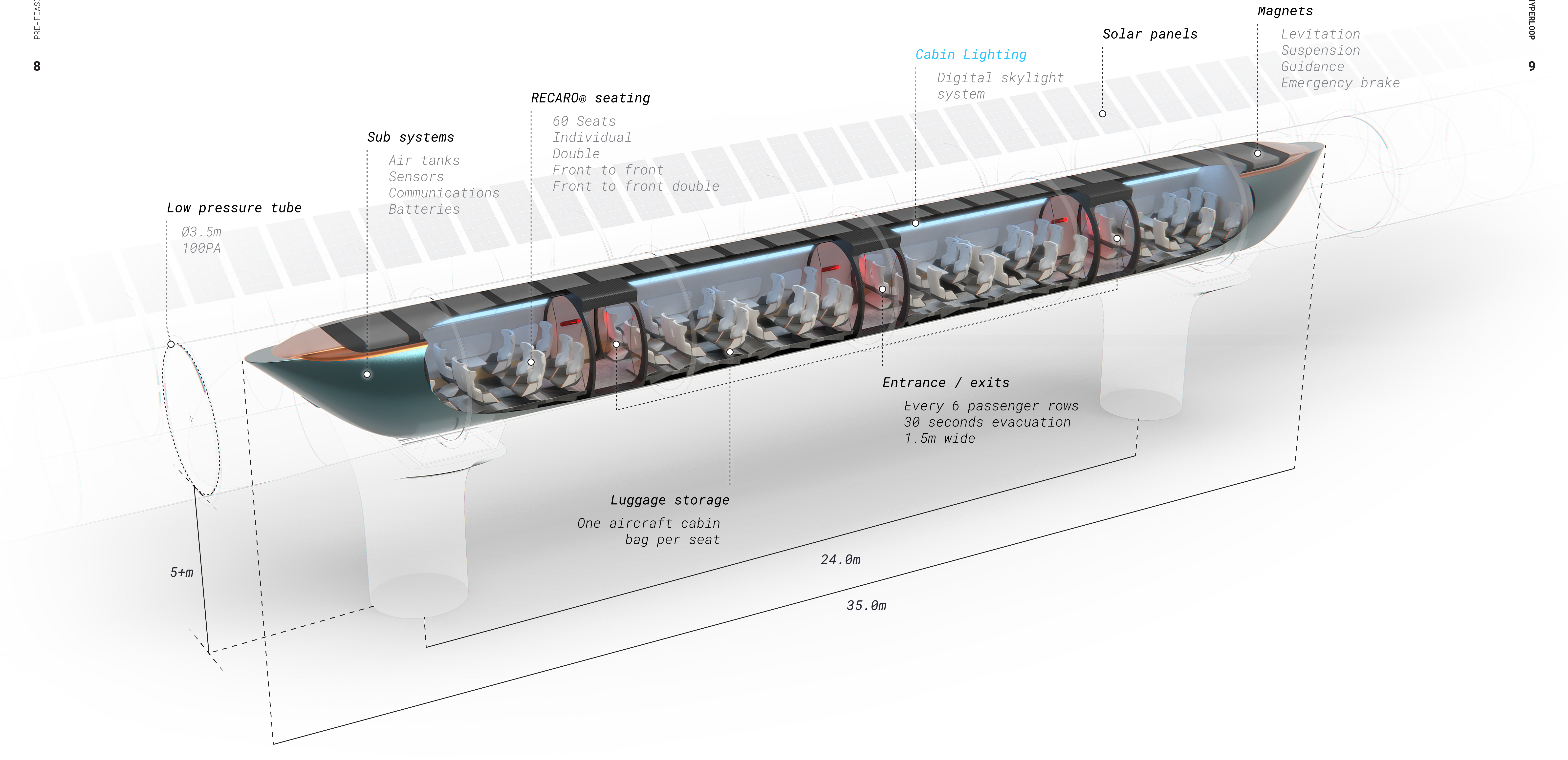


Figure 4. Overview of the Hardt hyperloop system

Figure 5. Hardt's Low-Speed Test Facility with the first prototype of the lane-switch.

PROOF OF CONCEPT

Hardt Hyperloop is leading the European developments of hyperloop technology thanks to its establishment of the first European full-scale hyperloop test facility. Additionally, Hardt has been successful at establishing a broad range of partnerships with relevant stakeholders within the transportation and technology sector, whose expertise is being leveraged during product development. This gives Hardt Hyperloop a unique knowledge base regarding the design and engineering of hyperloop technologies and their interfaces, as well as with the actual production, construction and operation of such a system. What's more, Hardt Hyperloop is the only company in the world that has proven hyperloop lane changing technology, which is crucial for the implementation of a hyperloop network. The lane changing technology allows hyperloop vehicles to change from one lane to another without any additional, or moving components. This enables the vehicles to retain their high speeds, effortlessly switch routes, and merge in and out of the network. Hardt Hyperloop has also developed unique software for the control of a hyperloop vehicle.

HYPERLOOP AS A SUBSTITUTE FOR SHORT-HAUL FLIGHTS

By 2050, Amsterdam Airport Schiphol's (AAS) capacity to handle flights will be restricted, putting pressure on the high quality of the network. Aviation passenger demand is projected to grow at a higher rate than the airport can accommodate, according to WLO scenarios. And by 2050 it is calculated the airport will be unable to facilitate expected passenger numbers, up to 58 million annually.

This case study presents hyperloop as a sustainable means of transport that could contribute to the growth of AAS as part of a balanced approach. It focuses on sustainable ways to accommodate aviation demand, reduce airport congestion and maintain the competitive position of AAS as an international multi-modal hub.

	AMS	BER	BRU	KLN	DUS	EIND	FRA	HAM	LON	PAR
AMS	-	63	21	24	19	11	36	52	58	47
BER	63	-	62	47	44	52	60	34	99	89
BRU	21	62	-	22	19	10	35	51	37	26
KLN	24	47	22	-	4	12	13	36	56	49
DUS	19	44	19	4	-	9	16	33	56	45
EIND	11	52	10	12	9	-	25	41	47	36
FRA	36	60	35	13	16	25	-	49	72	61
HAM	52	34	51	36	33	41	49	-	89	78
LON	58	99	37	56	56	47	72	89	-	39
PAR	47	89	26	49	45	36	61	78	39	-

Indicative travel times between Origin and destination pairs in the network

Passenger projections for the proposed hyperloop network in 2050 (Million passengers)

	2050	
	LOW	HIGH
Aviation	**40.2 M**	**59.9 M**
Of which accommodated at AAS	12.1 M	12.5 M
Of which unaccommodated at AAS	0.3 M	5.9 M
Of which through the rest of the network	27.8 M	41.6 M
Rail	**56.7 M**	**66.7 M**
Total:	**96.9 M**	**126.6 M**

PARAMETERS	VALUE
Network	
Total network length	2.200 km
Stations	18
System	
Tubes	2 (1 per direction)
Vehicle capacity	60 passengers
Vehicles per train	1-2
System capacity per hour	20.000 - 40.000 passengers / tube / hour
Vehicle load factor (%)	60-80%
Service Quality	
Vehicle cruise speed	700 km/h
Operating hours per day	16
Operating days per year	365
Reliability	Completely automated
Process time (at the terminal)	Shielded from external influences
	20 minutes

Table 1. Operational performance of Hyperloop

HOW HYPERLOOP WOULD AID IN SCHIPHOL'S SUSTAINABLE DEVELOPMENT AS AN INTERNATIONAL MULTI-MODAL TRANSPORT HUB

The study proposes an international cross-border hyperloop network between Schiphol and the major airports and cities of N.W. European countries, which fall within a 600 km radius. The proposed hyperloop network links five countries of Northwestern Europe. From West to East, the countries in the network would be: the UK, France, Belgium, The Netherlands, and Germany. The proposed network connects Schiphol airport with the main neighbouring airports that currently have direct flight connections. The network comprises a length of +/- 2.200 km, connecting a total of 18 stations (Airports and City stations), with hyperloop operating at an average speed of 700 km/h. In contrast to typical rail services, hyperloop services are direct between any origin and destination on the network without any intervening stops.

Based on WLO, the total estimated ridership for hyperloop accrues between 97 – 127 million passengers in 2050, of which +/- 12 million aviation passengers travel through Schiphol. Hyperloop is projected to decongest AAS by substituting 12.1-12.5 million passengers[5] in 2050. Because it allows for direct connections, the proposed hyperloop network could also supply services for passengers of both international and domestic trains, when they overlap with the same routes and corridors.

The peak-hour capacity utilisation rate ranges from 10% on the lower boundary (to Hamburg) to 40% in the upper boundary (Brussels – Eindhoven). After consolidating all passenger demand from aviation and rail through the proposed network, Hardt determined the peak-hour capacity requirements of each link in the network. This shows that based on international rail and aviation passenger segments; the system capacity exceeds demand in all links significantly. Upscaling/downscaling strategies for capacity based on demand and travel patterns include increasing / reducing headway, and vehicle linking.

[5] Based on extrapolation of the WLO scenarios.

What if other airports are also congested?

In this preliminary study Hardt assumes the other airports in the network grow following the unrestricted scenario. But demand is likely to surpass the limits of the adjustable capacity of EU airports from 2025 onwards. In fact, in the EuroControl Regulation & Growth (most likely) scenario of 1.9% annual average growth of passengers until 2040, it is expected that at least 2% of the demand will go unaccommodated in 2025, reaching 8% in 2040[6].

In the case that other airports in the network also become congested, in combination with a high demand growth, they face an opportunity cost of unaccommodated demand. The unaccommodated passengers could be accommodated by the hyperloop network, accounting for a potential of 11.8–18.5 million passengers in 2040-H and 2050-H respectively.

[6] Report EUROCONTROL: European Aviation in 2040: Challenges of Growth: Annex 1: Flight Forecast 2040: https://www.eurocontrol.int/sites/default/files/2019-07/challenges-of-growth-2018-annex1_0.pdf

ROUTE AMSTERDAM – BERLIN

Projected number of passengers per year in 2050:
Aviation: 1.5-1.6 million (restricted growth)
Rail: 0.9 – 1 million

Mode	Trip time (hh:mm)	Distance travelled	Energy use (TTW)	Environmental Impact (WTW)	Fare price
Aviation	1:16	596 km	387 wh/pkm	64 - 78 kg CO2*	79
HSR	6:05	614 km	61 wh/pkm	28 – 34 kg CO2*	79
Hyperloop	1:03	733 km	38 wh/pkm	23 - 33 kg CO2*	71

** per passenger*

EMBEDDING THE HYPERLOOP AT SCHIPHOL

Schiphol Airport is busy, and space is limited. The existing built environment dictates the possible locations for hyperloop. In the scope of this study, Hardt, Royal Schiphol Group and UNStudio conducted a exploratory study towards the spatial and operational implications of the Schiphol Hyperloop Terminal.

The Schiphol Hyperloop Terminal configuration is designed to accommodate at least the projected 12.5 million annual aviation passengers.
Schiphol Hyperloop Terminal Peak-Hour Passenger (PHP) demand in the 2050 low and high scenarios ranges from 2.500–3.000 passengers per peak-hour. The ratio Non-Schengen (London) and Schengen destinations is 50-50. Therefore, one platform will be dedicated to the Non-Schengen destinations, and one platform to the Schengen destinations (see table 2). On average 6-7 trains per hour depart/arrive per platform, resulting in a turnaround time per train of 7-10 minutes on average.

		WLO-2050-LOW		WLO-2050-HIGH	
Platform	**Destination**	**Arrivals**	**Departures**	**Arrivals**	**Departures**
1 (Schengen)	Berlin	18	18	19	19
	Brussels	5	5	5	6
	Cologne-Bonn	-	-	-	-
	Düsseldorf	5	5	5	5
	Eindhoven	-	-	-	-
	Frankfurt	17	17	18	17
	Hamburg	9	9	9	9
	Paris	28	29	29	30
2 (non-Schengen)	London	90	89	94	93
	Total:	**172**	**172**	**178**	**177**

Table 2. Daily vehicles arriving and departing to other cities in the network from AAS in 2050-low and 2050-high

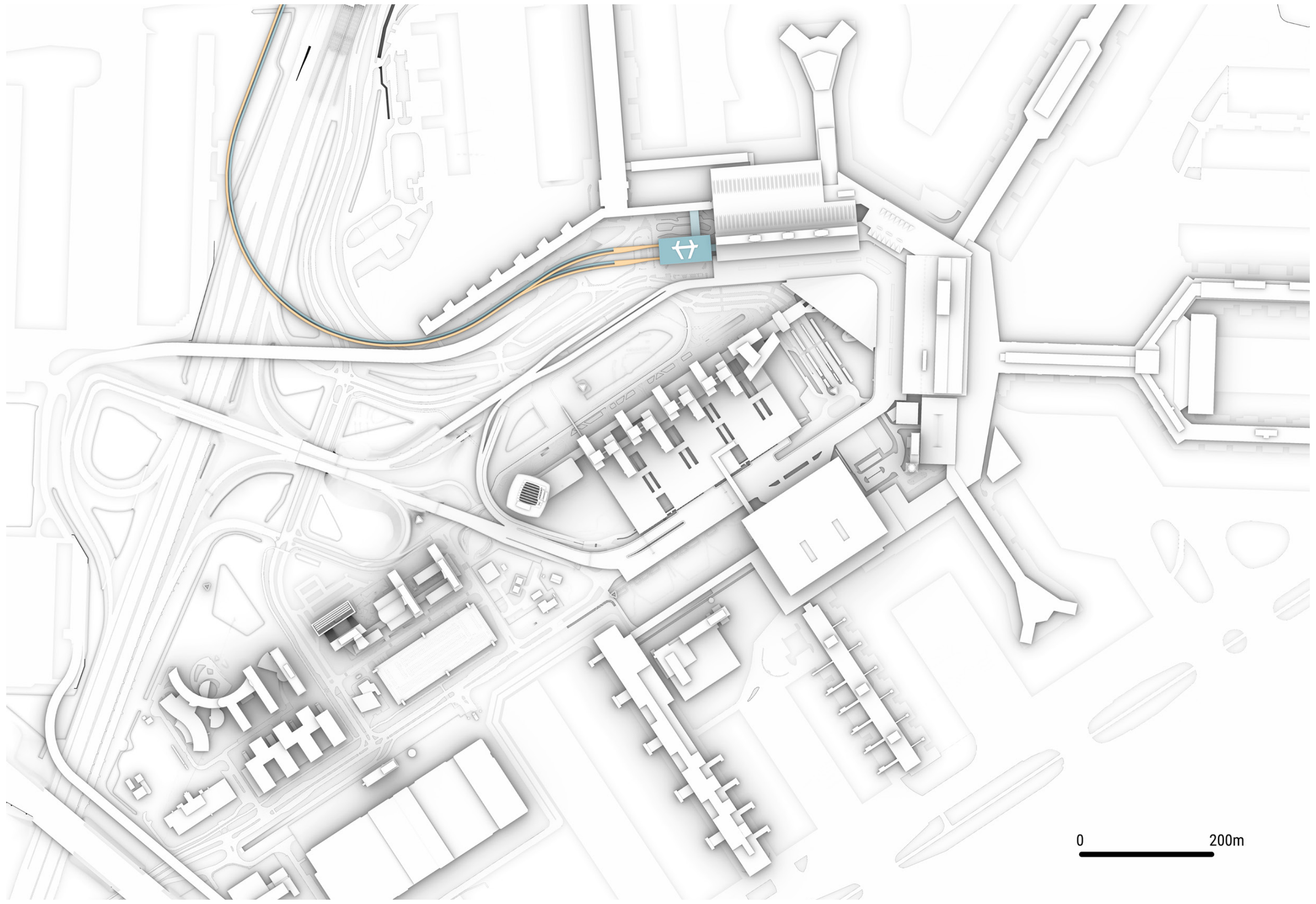


Figure 6. Indicative location at Schiphol Terminal West (UNSTUDIO)

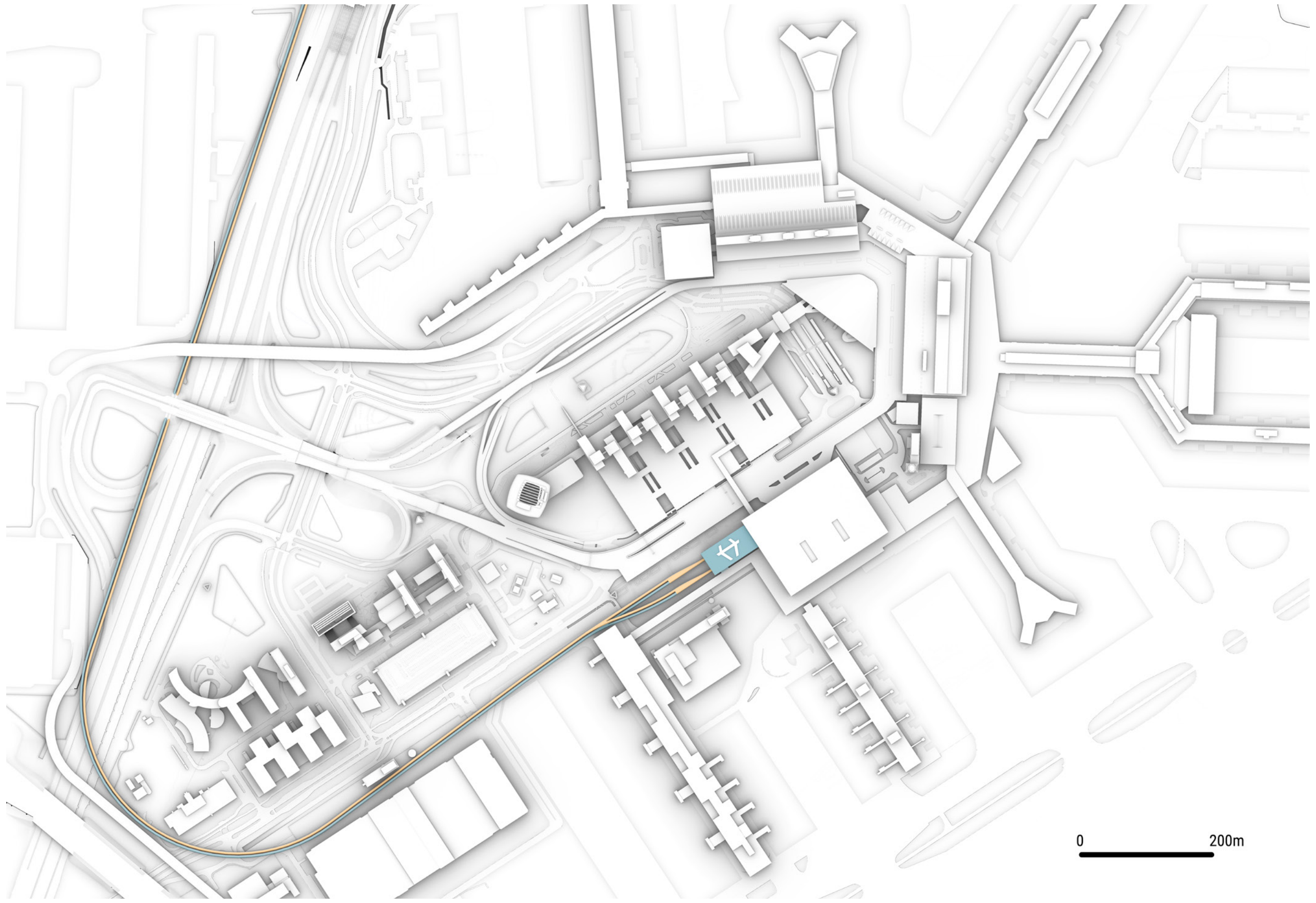
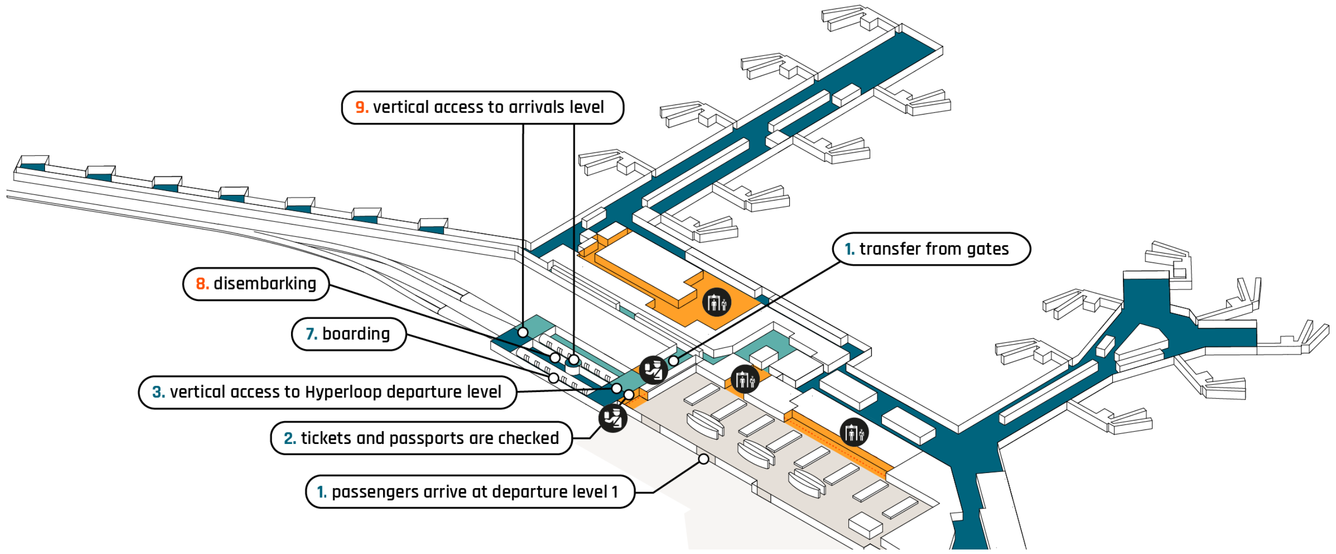


Figure 7. Indicative location at Schiphol Terminal A (UNSTUDIO)

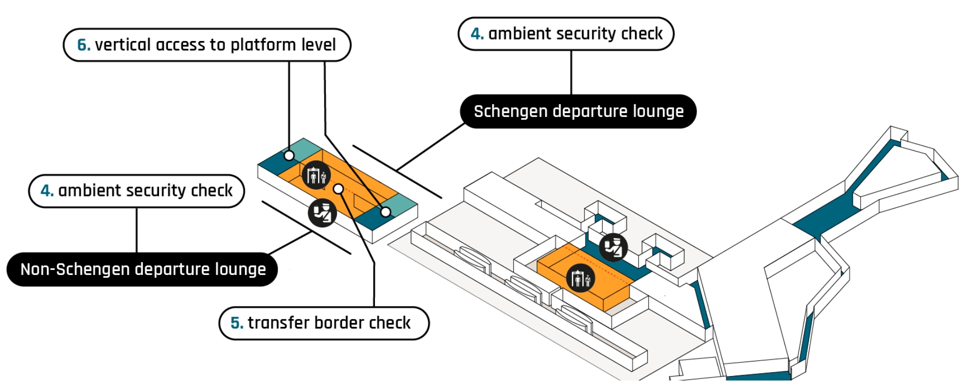
Schiphol level 1 departures

Hyperloop platform level



Schiphol level 2 departures

Hyperloop departure level



Schiphol Plaza arrivals

Hyperloop arrivals level

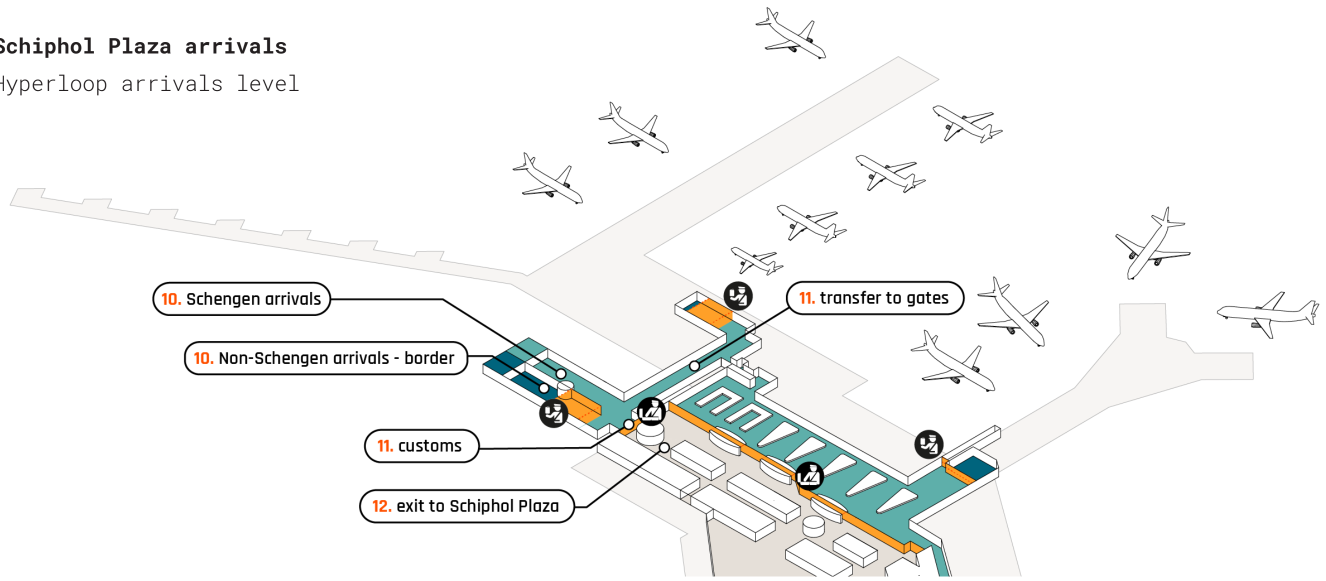
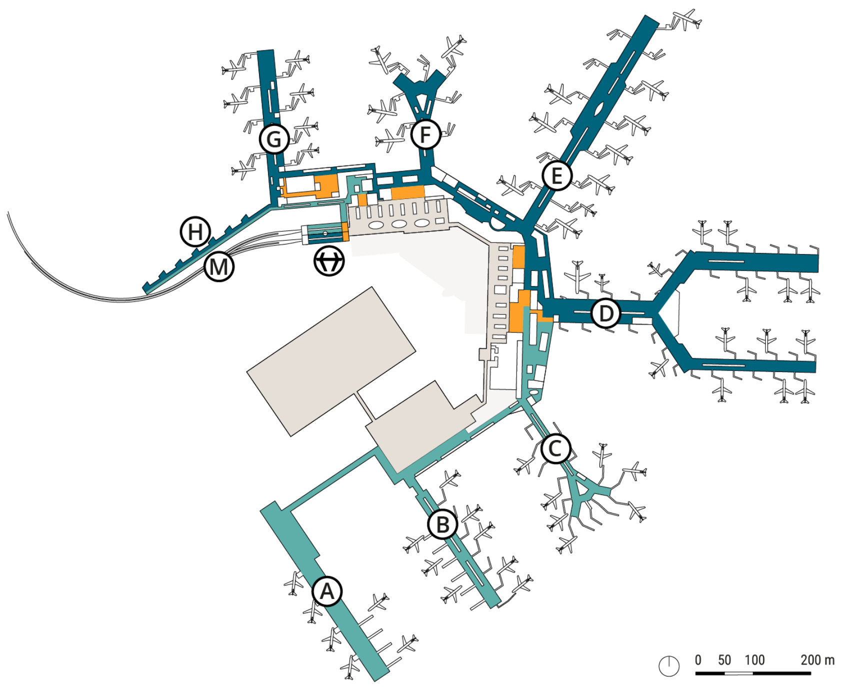
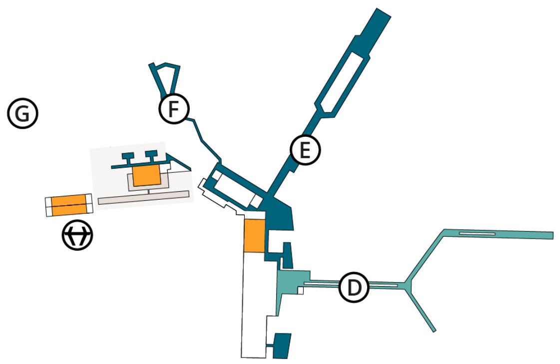
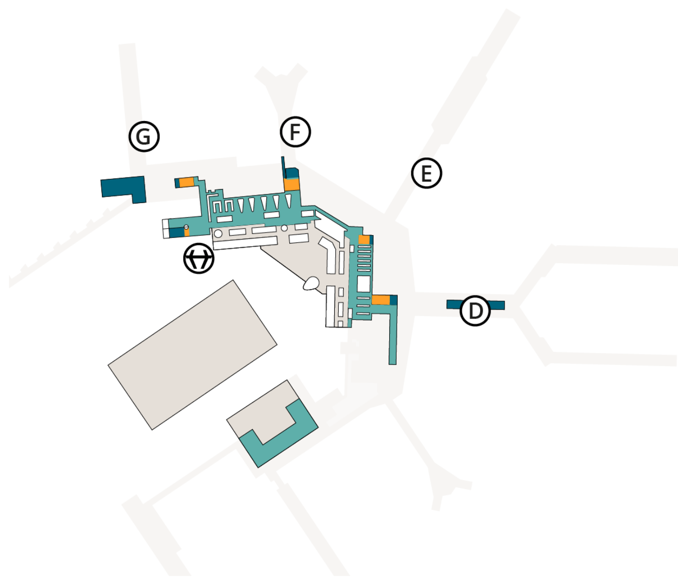


Figure 7. Concept hyperloop terminal layout at indicative location at Schiphol Terminal West currently Excellent parking (UNSTUDIO)







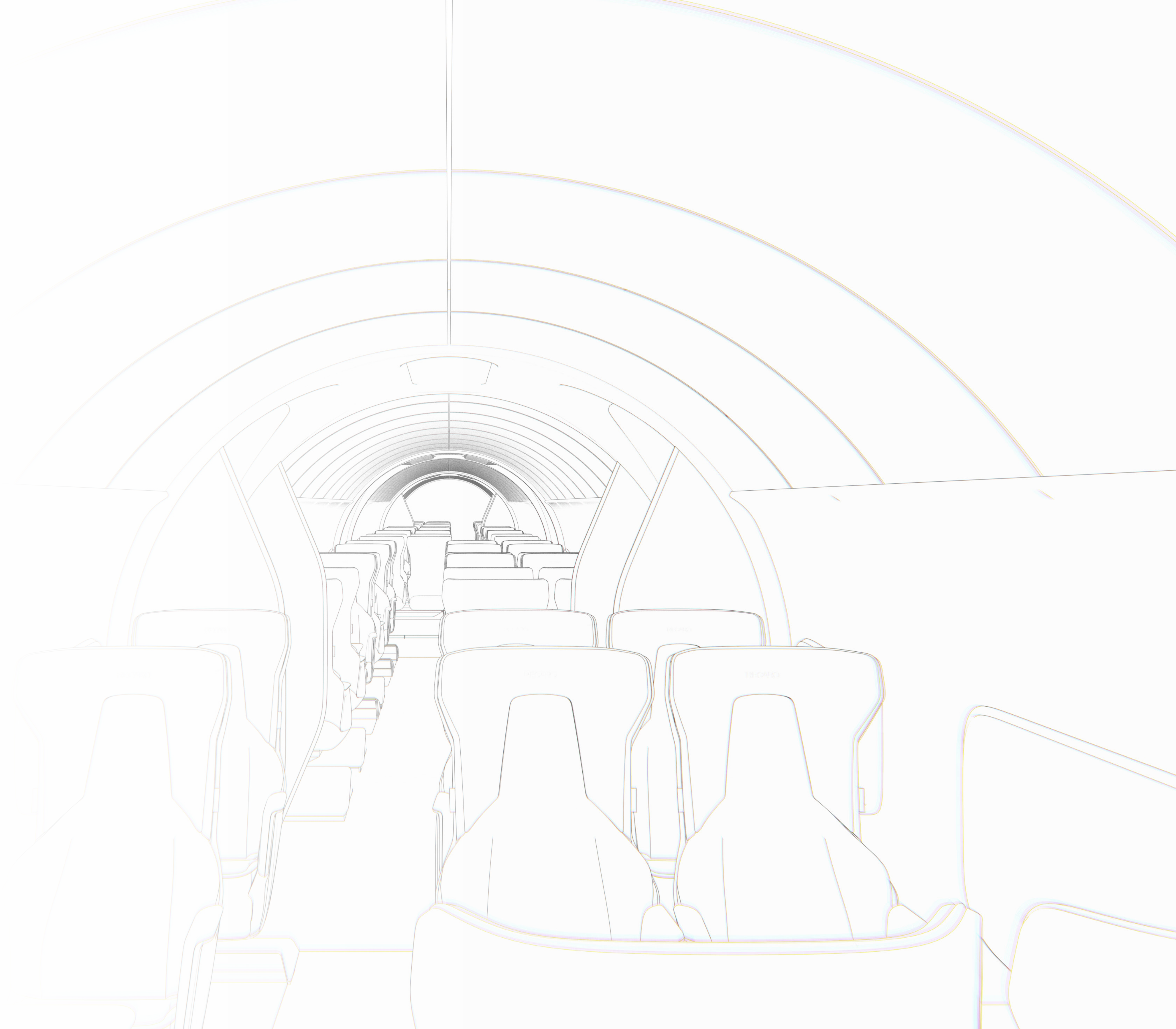
END NOTES

The study is executed in collaboration and consultation with stakeholders within Royal Schiphol Group and industry partners. A big thank you to all partners and contributors for their valuable input and expertise.

Pre-feasibility study
Schiphol-Hyperloop

Prepared by: Hardt Hyperloop
In collaboration with: Royal Schiphol Group

Partners and contributors to the study:
BAM, UNStudio, CE Delft, Stibbe, AirportCreators, SEO Amsterdam Economics (Advisory Role).



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