# CAPEX comparison: hyperloop vs. high-speed rail

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**On behalf of Hardt Hyperloop**

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# Executive summary

This document provides an outline of all major capital cost components of hyperloop and high speed rail (HSR) for comparative purposes.

It outlines costs for:

- the superstructure;
- the different civil infrastructure topologies;
- the vehicles, and
- qualitative considerations on the total implementation cost of either mode.

To provide a simple and indicative comparison, the modes are compared using a reference route. This route is composed of infrastructure that is:

- 50% at-grade;
- 30% elevated at a 20-meter span;
- 10% elevated at a >50-meter span, and
- 10% underground.

The above composition of a route leads to the following indicative overall average cost:

- **Hyperloop: €24.6 million per kilometer.**
- **HSR: €27.8 million per kilometer.**

Based on these cost estimations, the infrastructure costs of hyperloop and HSR are within a similar order of magnitude.

The vehicle costs of hyperloop and HSR are compared for a bi-directional reference route of 500 kilometers, and a capacity requirement of 7,500 seats per hour, per direction. The vehicle costs are based on the fleet required to meet this capacity requirement. For the reference route, the estimated fleet costs are:

- **Hyperloop: €4.0 billion.**
- **HSR: €4.6 billion.**

Other qualitative cost considerations identify a variety of capital cost advantages for hyperloop compared to HSR. The hyperloop superstructure can be produced off-site, with major benefits for the construction cost. In addition, hyperloop's superstructure, civil infrastructure, stations and depots are smaller. These characteristics allow hyperloop to be more easily integrated into the spatial environment compared to HSR.

# Comparison: hyperloop vs. high speed rail

## Introduction and reading guide

This document provides an indicative capital cost comparison of hyperloop and high speed rail. The comparisons consider the key types of infrastructure needed to implement a route. The comparison is a result of a collaborative effort between Deutsche Bahn E.C.O Group and Hardt Hyperloop.

In practice, the cost of transport infrastructure projects are heavily dependent on a variety of context dependent variables. However, given the indicative purpose of this document, the choice is made to focus on average circumstances. The comparisons consider average cost estimates that must be interpretated in "orders of magnitude." To ensure a fair comparison, all cost estimations consider the same underlying assumptions as much as possible.

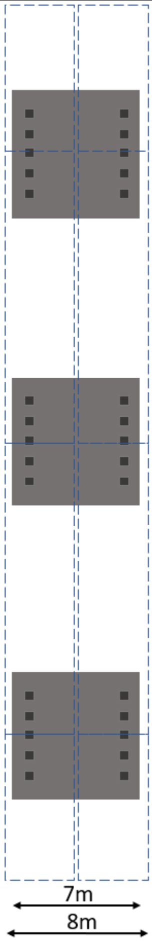
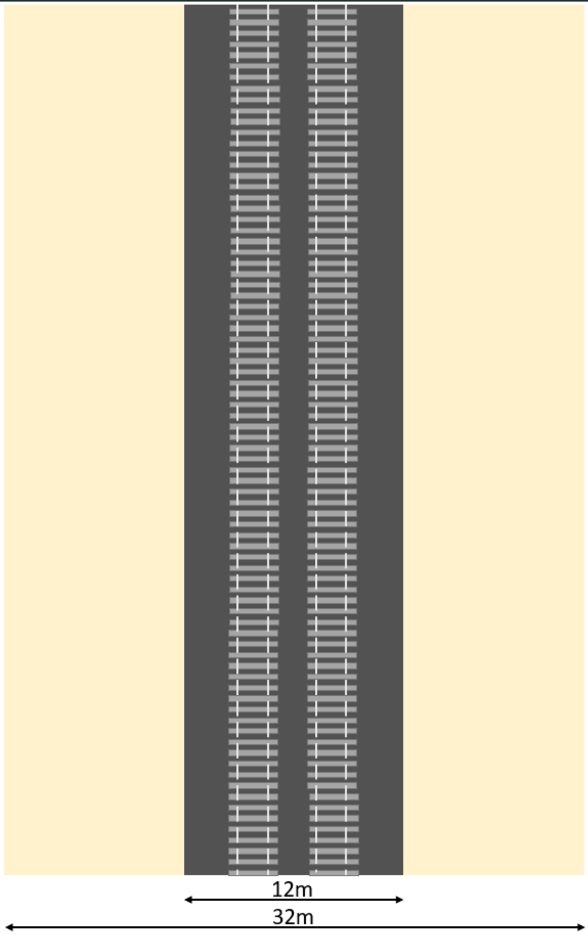
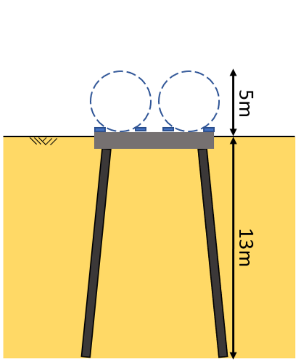
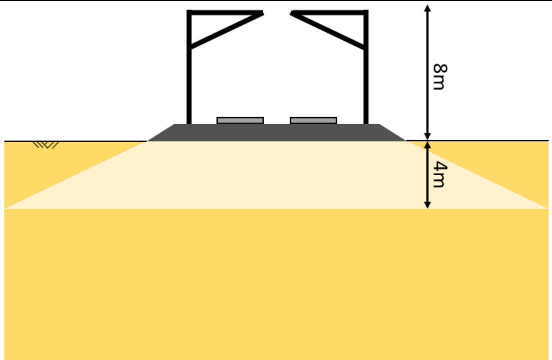
The comparisons consider hyperloop and HSR infrastructure:

- at-grade;
- elevated, and
- underground.

For elevated infrastructure, a distinguishment is made between a short and long bridge. Each infrastructure comparison considers a plan view, cross-section, and cost estimation of either mode. Cost estimations consider the total capital cost, including manufacturing and construction.

The comparisons also consider vehicle costs, as well as qualitative cost considerations. These qualitative considerations cover important notions that could not be captured in the quantitative overviews. The considerations discuss the cost implication related to the substructure, tunnel, spatial integration, construction, and stations and depots.

## At-grade comparison

| At-grade[1] | Hyperloop | High-speed rail |
|---|---|---|
| Plan view<br>60-meter section |  |  |
| Cross section |  |  |
| **Total cost [€/km]** | **21,100,000** | **16,000,000** |
| Land acquisition[2] [€/km] | 1,600,000 | 6,400,000 |
| Earthworks[3] [€/km] | 1,500,000 | 3,200,000 |
| Guideway[4] [€/km] | 16,000,000 | 4,400,000 |
| Power and operations [€/km] | 2,000,000 | 2,000,000 |

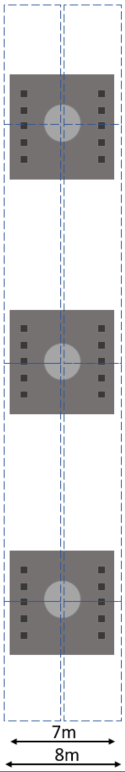
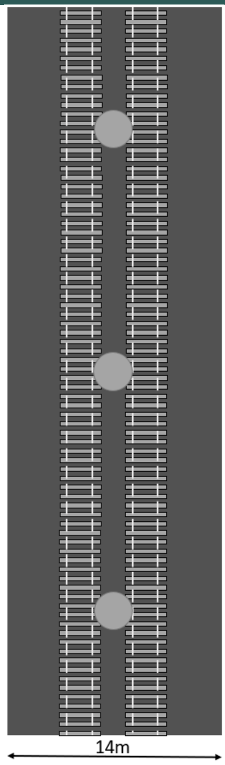
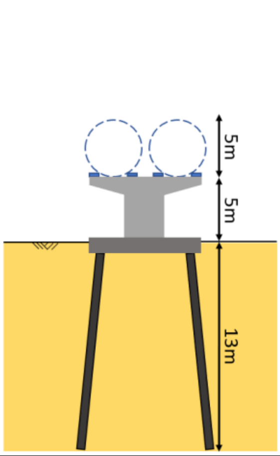
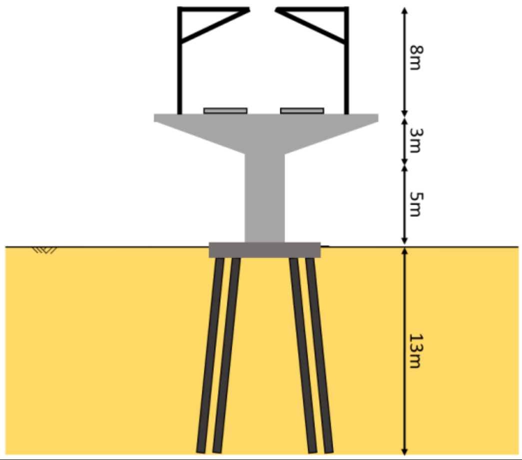
[1] *All cost estimates consider the total implementation cost for bi-directional infrastructure indexed for 2022 prices.*

[2] *Land acquisition at-grade (excl. service road): HSR 3.2 ha/km (DB) and HPL 0.8 ha/km (DB), with cost based on the average m2 price of empty construction land in Germany = 200 €/m2. Source: German Federal Statistical Office (2021).*

[3] *Earth works for Hyperloop are based on a foundation for a loadbearing layer at 13m below ground level. Earth works for HSR are based on the average for the German FDA 81 route.*

[4] *The guideway estimate of Hyperloop includes the cost for emergency exits.*

## Elevated comparison: short bridge (span of 20 meters)

| Elevated (20m span)[5] | Hyperloop | High-speed rail |
|---|---|---|
| Plan view<br>60-meter section |  |  |
| Cross section |  |  |
| **Total cost [€/km]** | **20,900,000** | **39,000,000** |
| Land acquisition[6] [€/km] | 400,000 | 400,000 |
| Earthworks[7] [€/km] | 1,500,000 | 3,200,000 |
| Elevated[8] (=20m) [€/km] | 1,000,000 | 29,000,000 |
| Guideway[9] [€/km] | 16,000,000 | 4,400,000 |
| Power and operations [€/km] | 2,000,000 | 2,000,000 |

[5] *All cost estimates consider the total implementation cost for bi-directional infrastructure indexed for 2022 prices.*

[6] *Land acquisition elevated (excl. service road): HSR 0.2 ha/km (DB) and HPL 0.2 ha/km (DB), with cost based on the average m2 price of empty construction land in Germany = 200 €/m2. Source: German Federal Statistical Office (2021).*

[7] *Earth works for Hyperloop are based on a foundation for a loadbearing layer at 13m below ground level. Earth works for HSR are based on the average for the German FDA 81 route.*

[8] *The estimate considers standardized sections for Hyperloop whilst custom bridges are considered for HSR.*

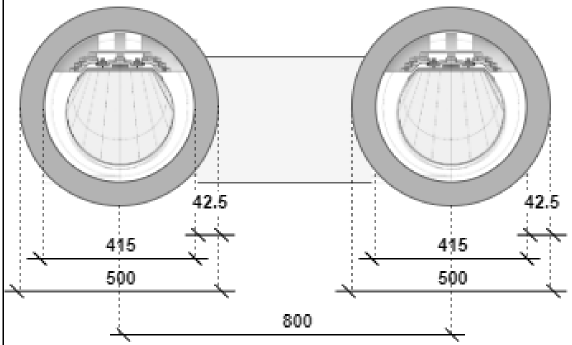
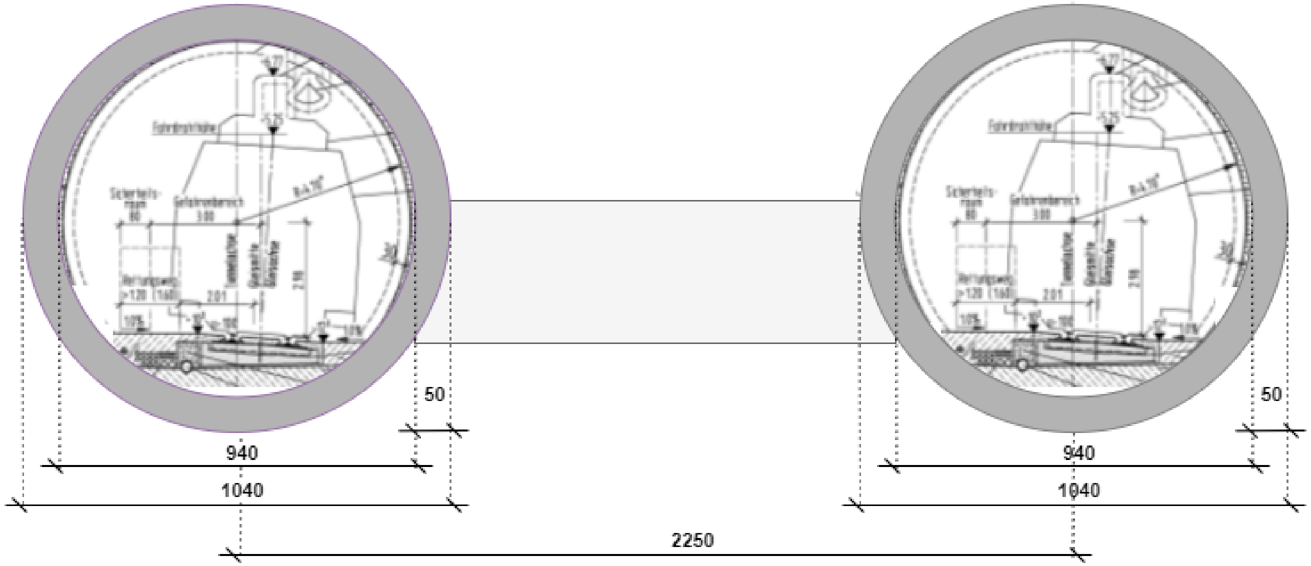
[9] *The guideway estimate of Hyperloop includes the cost for emergency exits.*

## Elevated comparison: long bridge (span of 50 meters or greater)

| Elevated (>50m span)[10] | Hyperloop | High-speed rail |
|---|---|---|
| Plan view | N/A | N/A |
| Cross section | N/A | N/A |
| **Total cost [€/km]** | **41,900,000** | **39,000,000** |
| Land acquisition[11] [€/km] | 400,000 | 400,000 |
| Earthworks[12] [€/km] | 1,500,000 | 3,200,000 |
| Elevated (>50m) [€/km] | 22,000,000 | 29,000,000 |
| Guideway[13] [€/km] | 16,000,000 | 4,400,000 |
| Power and operations [€/km] | 2,000,000 | 2,000,000 |

[10] *All cost estimates consider the total implementation cost for bi-directional infrastructure indexed for 2022 prices.*
[11] *Land acquisition elevated (excl. service road: HSR 0.2 ha/km (DB) and HPL 0.2 ha/km (DB), with cost based on the average m2 price of empty construction land in Germany = 200 €/m2. Source: German Federal Statistical Office (2021).*
[12] *Earth works for Hyperloop are based on a foundation for a loadbearing layer at 13m below ground level. Earth works for HSR are based on the average for the German FDA 81 route.*
[13] *The guideway estimate of Hyperloop includes the cost for emergency exits.*

## Underground comparison

| Underground[14] | Hyperloop | High-speed rail |
|---|---|---|
| Plan view | N/A | N/A |
| Cross section |   |   |
| **Total cost [€/km]** | **36,000,000** | **42,400,000** |
| Tunnel[15] [€/km] | 18,000,000[16] | 36,000,000[17] |
| Guideway[18] [€/km] | 16,000,000 | 4,400,000 |
| Power and operations [€/km] | 2,000,000 | 2,000,000 |

[14] *All cost estimates consider the total implementation cost for bi-directional infrastructure indexed for 2022 prices.*

[15] *The tunnel cost estimate includes the cost for emergency exits that allows passage between the tubes and follows TSI regulations on tunnel safety.*

[16] *The tunnel cost is derived from a study done by the HM Treasury UK (2010) that shows a 1 to 1 correlation between tunnel cost and tunnel diameter: link*

[17] *The tunnel cost estimate is based on the Katzenberg tunnel of 9.6 km long, which can be considered an average tunnel length.*

[18] *The guideway estimate of Hyperloop includes cost for emergency exit to get from the tunnel to the surface.*

## Total CAPEX comparison for the reference route

| Reference route[19] | Hyperloop | High-speed rail |
|---|---|---|
| Plan view | N/A | N/A |
| Cross section | N/A | N/A |
| **Total cost [€/km][20]** | **24,610,000** | **27,840,000** |
| Superstructure [€/km] | 18,000,000 | 6,400,000 |
| At-grade = 50% | 1,550,000 | 4,800,000 |
| Elevated (20m) = 30% | 870,000 | 9,780,000 |
| Elevated (>50m) = 10% | 2,390,000 | 3,260,000 |
| Underground = 10% | 1,800,000 | 3,600,000 |

*[19] All cost estimates consider the total implementation cost for bi-directional infrastructure indexed for 2022 prices.*
*[20] The reference route is based on a meta study on high-speed rail projects by the Beijing Office of the World Bank (2014). From the study a distribution between at-grade, elevated and underground infrastructure is derived. To be conservative a high share of at-grade infrastructure is assumed. Source: World Bank (2014) : 892000BRI0Box3000china0transport09.docx (live.com)*

## Vehicle cost comparison

| Vehicles | Hyperloop | High-speed rail | Dimension |
|---|---|---|---|
| Plan view | N/A | N/A | *N/A* |
| Cross section | N/A | N/A | *N/A* |
| Total fleet cost (bi-directional)[21] | 3,984 | 4,590 | *[mil€]* |
| Route length | 500 | 500 | *[km]* |
| Peak demand (one-directional) | 7,500 | 7,500 | *[seats/h]* |
| Average speed | 500[22] | 225[23] | *[km/h]* |
| Turnaround time | 3 | 15[24] | *[min]* |
| Seats per vehicle | 35 | 450 | *[seats]* |
| Vehicles per train | 1 | 2 | *[vehicles]* |
| Seats per train | 35 | 900 | *[seats]* |
| Running time per train | 60 | 133 | *[min]* |
| Running time including turnaround per train | 63 | 148 | *[min]* |
| Train runs per peak hour (one-directional) | 215 | 9 | *[runs]* |
| Train headway | 17 | 400 | *[sec]* |
| Number of running trains | 226 | 23 | *[trains]* |
| Number of running vehicles (one-directional) | 226 | 46 | *[vehicles]* |
| Number of running vehicles (bi-directional) | 452 | 92 | *[vehicles]* |
| Maintenance spare | 10% | 10% | *[%]* |
| Total fleet size | 498 | 102 | *[vehicles]* |
| Cost per vehicle | 8,000,000 | 45,000,000[25] | *[€]* |
| Cost per seat | 228,000 | 100,000 | *[€]* |
| Total fleet cost | 3,984,000,000 | 4,590,000,000 | *[€]* |

[21] *Total fleet costs are determined for a bi-directional route of 500 kilometers, with a required peak capacity of 7,500 seats per hour, per direction.*
[22] *InnoEnergy (2022). High Level Business Case European Hyperloop Infrastructure - European Hyperloop Industrial Initiative.*
[23] *Average speed of HSR is determined without intermediate stops.*
[24] *Based on the turnaround time at the Tokyo Terminal including cleaning.*
[25] *Purchase cost IC3 train derived from Siemens source and calculated based on price index : UPDATE 1-Siemens, Eurostar ink 700 mln eur train deal -source | Reuters*

## Qualitative cost comparisons

The following qualitative cost considerations were determined collaboratively between Deutsche Bahn E.C.O. Group and Hardt Hyperloop, and refer only to the capital cost (CAPEX) of hyperloop and HSR.

**When comparing the hyperloop substructure to HSR:**

- At-grade, the hyperloop guideway is supported at intervals, making it easier to adjust for deviations resulting from soil settlements.
- The hyperloop guideway has looser tolerances, allowing its substructure to handle more soil settlements. As a result, the guideway is easier to implement independent of soil type.
- The hyperloop vehicle levitates magnetically and has a lower "vehicle-to-infrastructure" weight ratio. Even at higher speeds, it is expected that this will result in lower vibrational stresses on the civil infrastructure.

**When comparing the hyperloop tunnel to HSR**:

- A HSR tunnel is around twice the size of hyperloop tunnel.
- A hyperloop tunnel can have a much smaller tube diameter because it does not have to deal with the displacement of air.
- Smaller tunnel diameters can allow for faster construction (UK IPA, 2017).

**When comparing the spatial integration of hyperloop to HSR:**

- Hyperloop's infrastructure features a much smaller cross section, allowing for easier spatial integration.
- Hyperloop's guideway sections do not require custom bridges to cross roads and streams for a span of up to 20 meters.
- Hyperloop can achieve twice the speed at the same horizontal radii, making it easier to achieve higher speeds within a limited space.

**When comparing the construction cost of hyperloop to HSR:**

- Hyperloop's superstructure can always be assembled in factories off-site, resulting in lower construction costs. For HSR, off-site assembly is only possible for elevated route segments.
- Hyperloop infrastructure is much smaller, allowing for faster construction and lower implementation costs.
- Hyperloop's infrastructure requires less resources during construction, resulting in lower carbon emissions.

**When comparing the station and depots of hyperloop to HSR:**

- Hyperloop's stations require less space to facilitate the same passenger flows.
- Less depot space is required due to the smaller fleet size and higher handleability of pods.