Energy efficiency of Maglev vs High-speed-rail

Maglev has poor energy efficiency compared to high-speed rail. This is due to high electrical dissipation in the many coils, and the reduced efficiency of magnetism over a large air-gap.

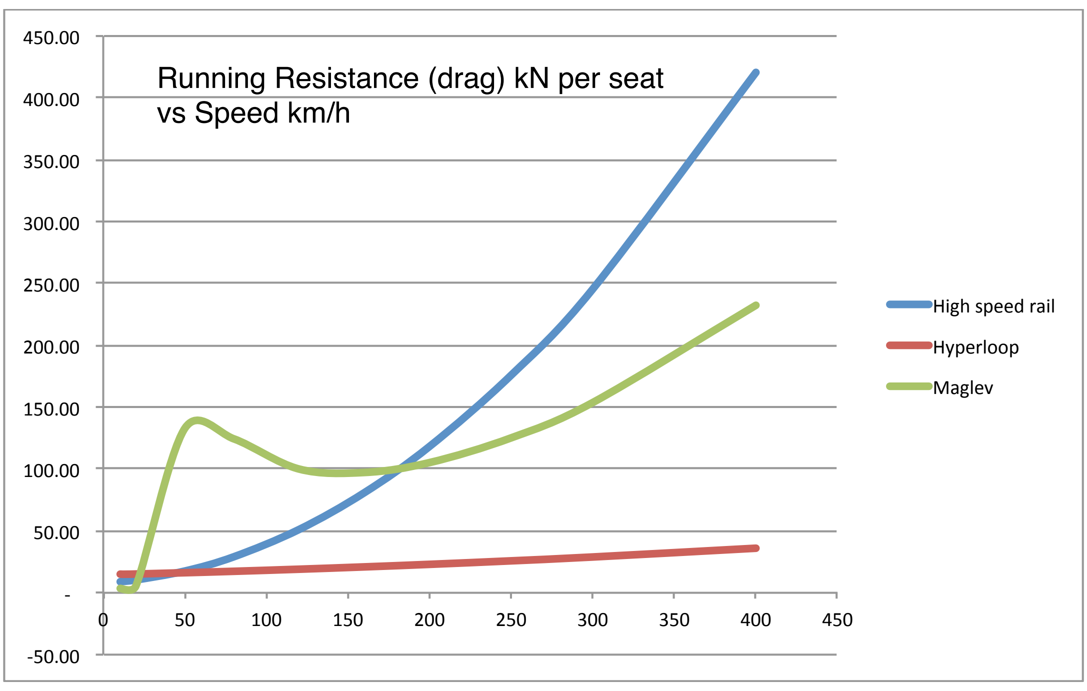
The following figures refer to the Transrapid maglev in Shanghia, China, the the only operational maglev. The SCMaglev in Japan which has similar speed has not published any energy data.

Electrical dissipation accounts for 3.6 times the energy loss compared to aerodynamic drag for the 29 km Shanghai route.

These are the electrical consumption, kWh per passenger seat 100km
- Transrapid maglev 19.9 kWh
- High-speed rail 7.7 kWh
- Tesla car (lower speed) 4 kWh

Maglev has always been promoted as the future of high-speed transportation, with frictionless and wear-free suspension. But with very high construction costs and poor energy consumption in service, it can be seen why maglev has not been commercially successful.

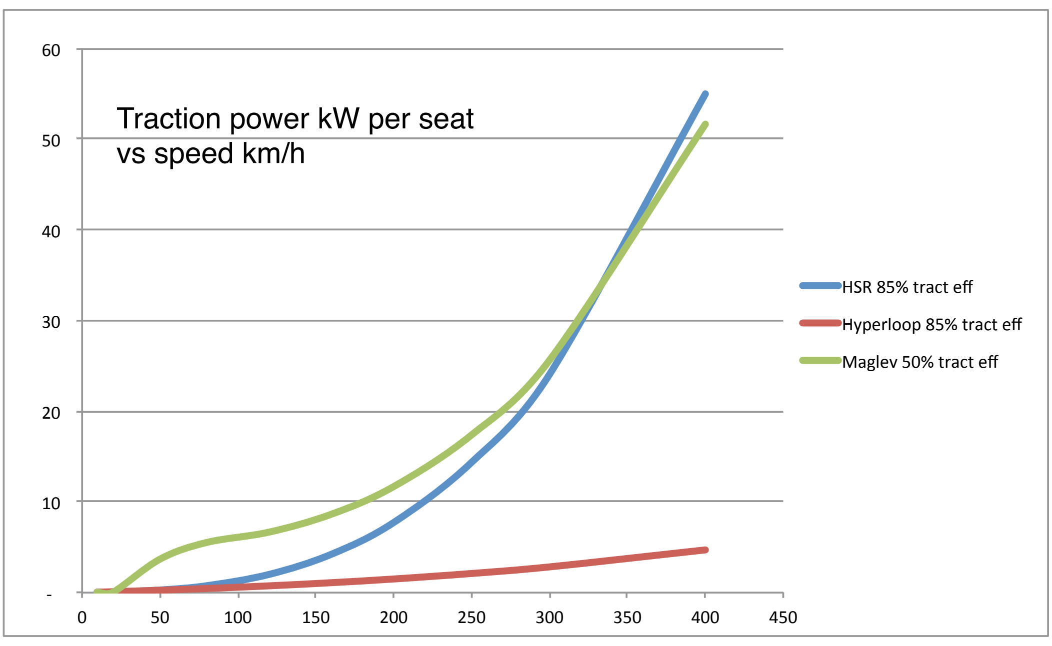
Running resistance (drag)



The chart shows the running resistance for the maglev and train, divided by the number of passengers seats so they can be compared. The maglev shows very high drag at lower speeds, reducing at high speeds compared to the HSR. The better high-speed drag might be due to the very clean aerodynamics of the Transrapid.

The chart also shows the estimated drag for a Hyperloop system, 27 seats in a 10-ton pod, using tires with a 250:1 L/D. Steel wheels have the advantage at low speeds, but Hyperloop is much more efficient at high speed due to the light weight and minimal aerodynamic drag in the vacuum.

Low traction efficiency requires increased traction power



The running resistance (drag) chart showed the maglev train having the advantage at higher speeds. But this changes when we apply traction to overcome the resistance. The Linear Synchronous Motors in the maglev have low efficiency, partly due to dissipation in the many coils in the active track section, and partly due to the wider air-gap which is necessary for bump absorption. This chart shows the kW per seat, using 50% traction efficiency for maglev, compared to 85% traction efficiency for the HSR and Hyperloop. Note the very high power consumption for maglev at lower speeds.

On-Board Power
The Transrapid has very poor energy efficiency below 150 km/h, due to the method of generating on-board power, which is necessary for levitation and air conditioning etc.

It uses a linear generator to generate on-board power, which has limited efficiency. But this requires extra thrust from the linear motors which provides traction for the train. These also have limited efficiency, so the on-board power suffers the inefficiency of two linear systems. At 120 km/h, 70% of the energy loss is due to the inefficient on-board power generation. If the train used overhead lines for its on-board power, it could have much higher efficiency.

Kinetic loss due to traction efficiency.

Any vehicle with extended acceleration and braking will be subject to the efficiency of its traction systems. Kinetic loss is likely to be the biggest energy cost for Hyperloop, with its high speed and low drag.

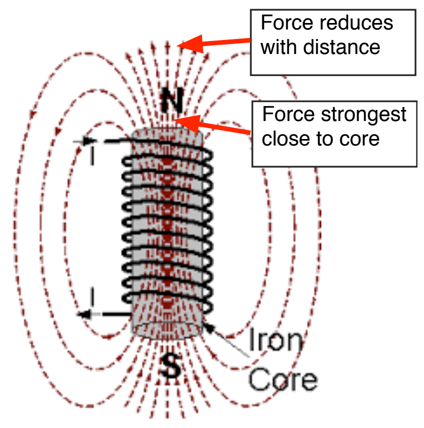
Accelerating to a high speed requires considerable power input, which is only partly recovered by regenerative braking due to limited efficiency. If we had a traction efficiency of 90%, and a regenerative braking efficiency of 80%, our overall kinetic loss would be about 30% of the kinetic energy which is $0.5mv^2$. The braking efficiency is increased with a lower braking rate, so that more of the energy is efficiently absorbed into overcoming drag. A car coasting to a stop has zero energy loss in braking.

Part of the high energy consumption of maglev is due to its low-efficiency traction and regenerative braking, so that there is a large kinetic energy loss from the high speed over a short route.

Increased track clearance reduces efficiency

Maglev requires quite large clearance between the track and coils on the train, to allow for variations in the alignment of the track.

Because magnetic force reduces with distance, a greater current is required to provide the same force. Increased current leads to increased dissipation and reduced efficiency. Conventional electric motors have small clearance for maximum efficiency.



Sources on next page

Sources

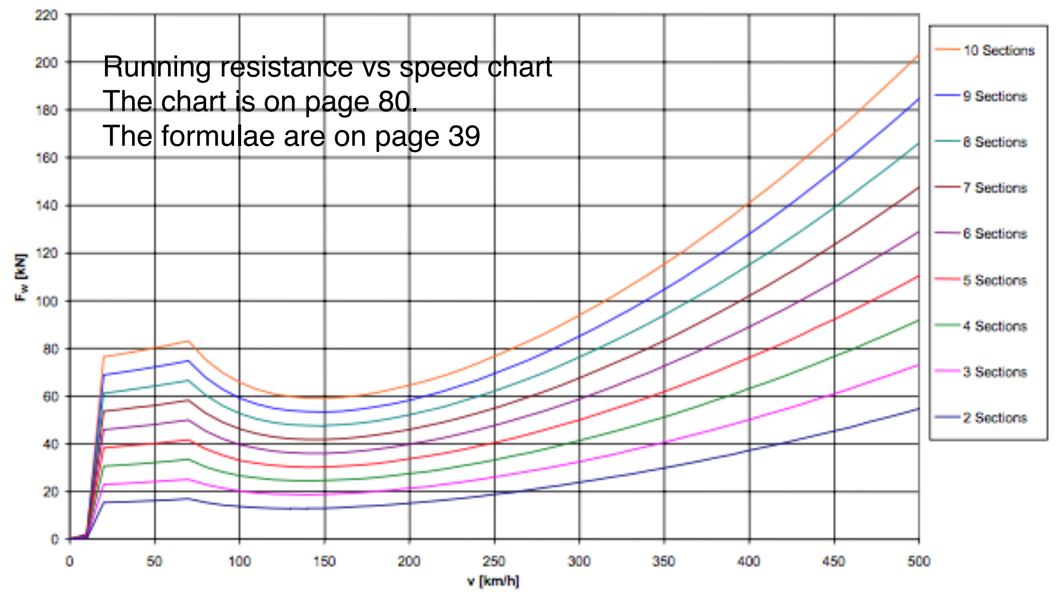
It is virtually impossible to find energy consumption figures for high-speed rail, and even harder for maglev. Cars and modern aircraft are proud of their energy efficiency, and publish reliable figures to sell their products. The railway industry relies on the public perception of low energy consumption, and are unwilling to publish real figures to the contrary. The SCMaglev system in Japan has never published any data, but fortunately there are some figures available for the Transrapid system in Shanghai.

Maglev energy data

http://magnetbahnforum.de/phpBB2/viewtopic.php?topic_view=threads&p=46579&t=8962

This is a discussion by John Harding, former US Maglev Chief Scientist. It contains a link to the Transrapid Design Principles PDF.

"The 29.3 km, 430 km/h max trip of a 5 car Transrapid at Shanghai requires 1.75 MWh of electrical energy. This represents a LSM efficiency of 25.4% based on the train resistance formulas in the attached (p.39). Aerodynamic drag amounts to .313 MWh or only 18% of the total energy. Dissipation in the windings and feeders accounts for 1.13 MWh! Interestingly, the poor performance is the result of the non-contact nature of the propulsion system. If the energy were supplied from an overhead catenary at 25 or 50 kV, the motor efficiency could be as high as 90-95%".



Total running resistance:
$F_W = F_A + F_M + F_B$

Aerodynamics:

Magnetisation:
$F_M = N * (0.1\ kN * (v/[m/s])^{0.5} + 0.02\ kN * (v/[m/s])^{0.7})$
applies when using the recommended material for the lateral guide rails according to Chapter 0.

On-board power generation:

$F_B = 0$	for 0 to 20 km/h
$F_B = N * 7.3\ kN$	for 20 to 70 km/h
$F_B = N * (146\ kN / v/[m/s] - 0.2\ kN)$	for 70 to 500 km/h

where
v - velocity of MSB vehicle
N - number of vehicle sections

High-Speed rail resistance

https://pdfs.semanticscholar.org/b2a1/478bb878493fb4eee06e89f847d80e649309.pdf

The resistance formula for the high-speed rail are on page 10, and the data on page 21.

Experimental findings show that the sum of mechanical resistance (on straight track) and aerodynamic drag can be quantified, [4], [14], [15], [19], [37], [38], [54], with adequate accuracy by:

$$F_R = F_M + F_D = A + Bv + Cv^2 \qquad (2\text{-}1)$$

The coefficients *A*, *B* and *C* are however not constants; they vary with type of train, track, wheel-rail friction etc.

Table 3-4 High speed trains. Train data and resistance coefficients.

Train	Config	Axles	Tot. mass (tonnes)	Length (m)	Track type	*A* (N)	*B* (Ns/m)	*C* (Ns^2/m^2)
X2-5	pu + 3 cars + pu	20	300	109	4	1600	51.6	6.22
X2-7	pu + 5 cars + pu	28	398	159	4	2300	57.8	7.74
X2	pu + 4 cars + dt	24	318	139	1	2000	40.0	6.90

High-speed rail energy

The energy consumption figures come from an Australian HSR feasibility study

https://infrastructure.gov.au/rail/trains/high_speed/files/HSR_Phase_2_Appendix_Group_4_Cost_and_program.pdf
See pdf page 50 (Appendix 4C page 2).
Using 40 kWh per train km, for a 520 seat train.
7.7 kWh per passenger seat 100 km.