Sustainable Transportation Systems
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Lecture 49
Emerging Transport Technology - Hyperloop

Hello, friends. So, we have discussed several transportation systems and technologies within the, this purview of sustainable transportation system. And today we will discuss about some emerging transport technologies, which are like, the growing technologies, which will be the normal technology of the transportation in future. So, today we will discuss about the Hyperloop.

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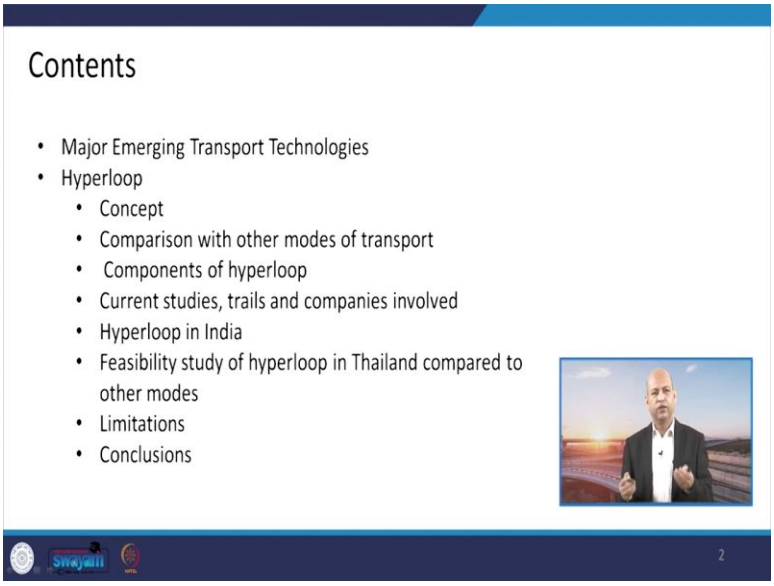

But before that, we can see like what are the major emerging transport technologies these days. And then we will discuss in detail about the Hyperloop, we will focus our lecture on Hyperloop related concepts and then the comparison with other modes of the transport and components of Hyperloop, which are very important for designing purpose, and then the current studies and trails or trends and the companies which are involved in this new technology of the Hyperloop.

And within India what are the projects which are linked with the Hyperloop, and then the feasibility study of Hyperloop in Thailand compared to other modes. So, that is also one data set, we will discuss. Then we will also discuss like limitations of this new technology in, those kinds of limitations, how can we overcome those limitations in future? Otherwise, how can we address those limitations? And then we will conclude.

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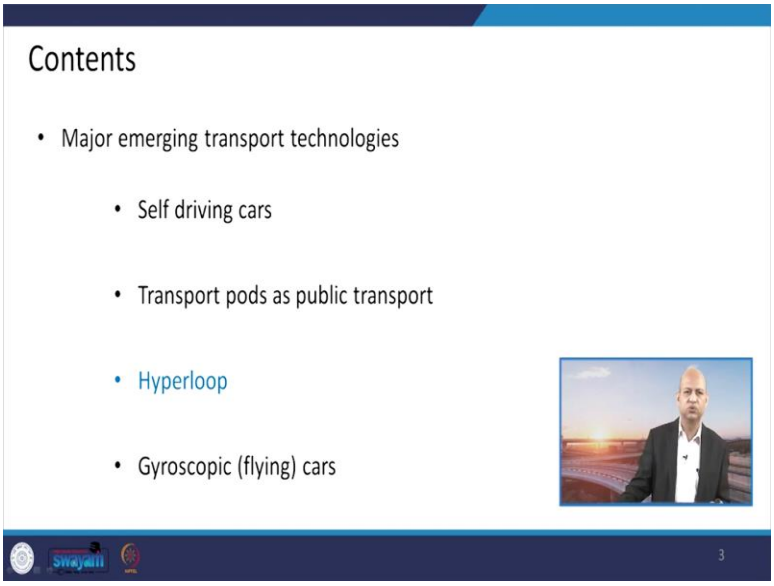

So, when we talk about major, emerging, or new transport technologies then you might have read several articles in the newspapers and also social media or these popular media, like self driving cars. Google related self driving cars, you must be knowing about. So, that they are being trained by some software some sensors as well as GPS system.

Everything is there and it can take you from one place to another place with the given coordinates and it takes care of all that turns and everything. Even it saves you from any kind of possible accidents and those kinds of things are there. So, this is one very important development in the sector. Then transport pods as public transport. So, these are different than the simple high-speed rails or means cars et cetera. These are, in, different in the sense of their carrying capacity, their speed and their size et cetera.

Then one is Hyperloop which we will discuss in detail just now. Then there are like flying cars also. The cars which are able to like fly from one place to another. So, these kinds of experiments are going on. It is said that Israel has already developed this flying car. So, some prototypes are there, some are in very nascent stage of the development, but they may be like normal transportation mode in the future.

And because, every time when we develop a new kind of technology then there is a period of inertia when investment is needed in big quantity, plus infrastructure are needed, like, electric cars we are talking nowadays, but unless infrastructure is in place, its popularity will take time, but it is one thing which is coming very fast. But we will discuss like, Hyperloop.

Otherwise drones also. Like, you might have read I think in Telangana they have tried to transport medicines from one place to another. So, those kind of transportation of goods or services can be through drones. Plus, also there are other like, flying this kind of new technologies are also coming.

But basically, today we will discuss about Hyperloop as a case study so that you can get excited about the new technologies and you can also think in different way, in out of box way and maybe you can devise some new technology which can be part of the future technologies of the transportation.

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Well, so what is Hyperloop? When we talk about the Hyperloop, so this is basically consists of is sealed tube. One tube means, big pipe, you can imagine. And this is a system of tubes with very low pressure inside, so that friction is bare minimum. And through which, a pod or, like you can say, one wagon or, or that kind of capsule is traveled, or it can travel at a very, very high speed. It is, even you can compare it with the aeroplane.

And due to the unique feature, it is also termed as like fifth mode of transportation. So, you can see, one, this cross section is there. So, this is the outer form of the tube and within this tube, this is the capsule or you can say this is the pod, which is taking passengers from one place to another.

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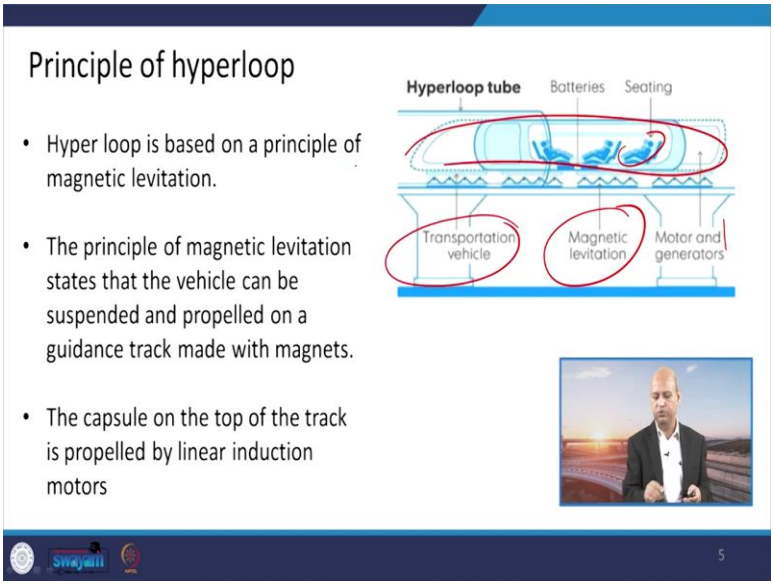

Well, the principle which are kind of fundamental thing to design the Hyperloop or on which it works. So, this is basically based on a principle of magnetic levitation. So, it, it is like in the air it, on a cushion kind of something. It does not touch the surface and it travels in the air, and, on some height, you can say.

The principle of magnetic levitation states that the vehicle can be suspended in the air. You can suspend it, nor the touching. And it can be propelled on a guidance track made by the magnets, made with the magnets. The capsule or the pod, on the top of the track, is propelled by linear induction motion.

So, those kinds of fundamental principles are used. You can see here. These are shown, like batteries are there, then seating arrangements are there, magnetic levitation, you can see here, and then the motor and generators are there, transportation vehicle, which is the, this capsule, you can see. So, all these parts are there.

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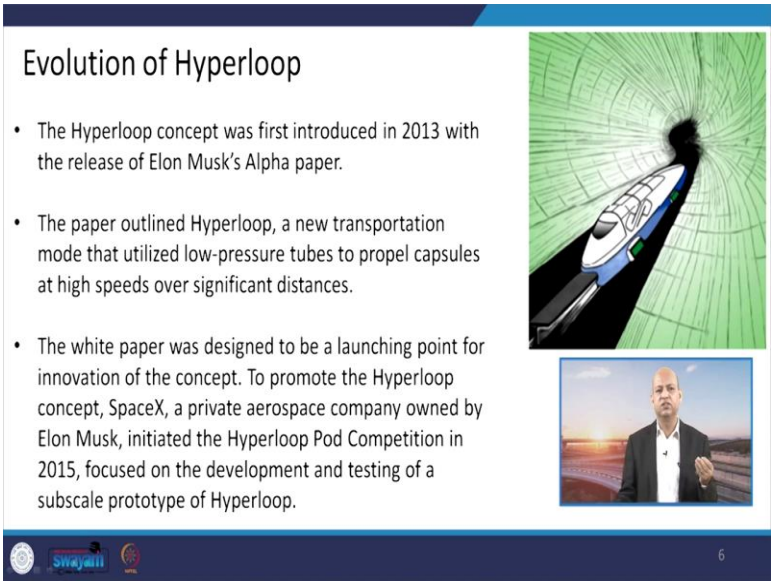

And this is another part of like evolution. How this cyber loop really evolved in terms of transportation mode or transportation system. So, basically the concept of the Hyperloop was first introduced in 2013 with the release of Elon Musk's Alpha paper. We have given the reference of this at the end. You can go through in detail. It is more than 50 pages. So, it has given complete design, the principle, very small calculations, concept, everything is there.

And this paper, which outlines the Hyperloop, the new transportation mode which we talked about, and utilize low pressure tubes, as we have already discussed, to prep, to propel the capsules at high speed over significant distances, means larger distances. And this white paper it was designed for launching point of the innovation of this concept, and it was not like patented something, it was an open space so that people can further improve upon those concepts which it has been discussed in the, in this particular paper.

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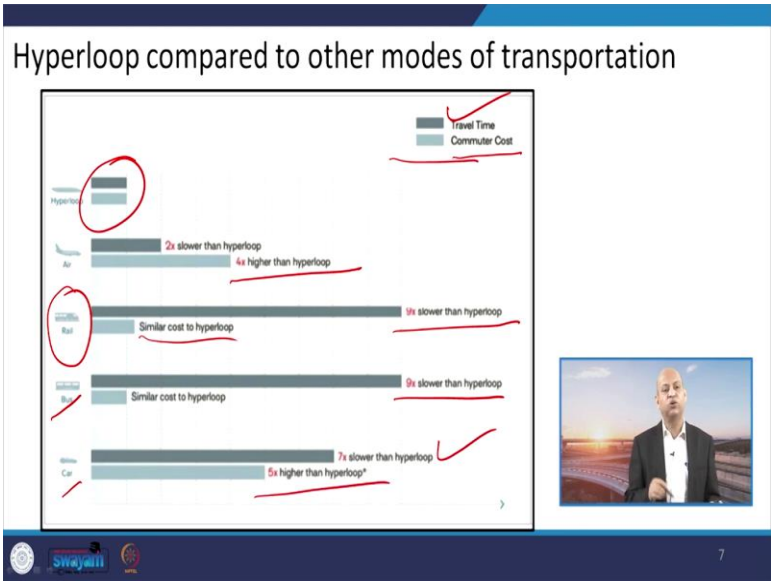

Well, when we talk about like a comparison of the Hyperloop to other modes of transportation, so this pictorial representation gives a clear case, clear cut case that the Hyperloop is very much low in cost and very high in the speed. You can see this is the Hyperloop related travel time in dark color, and in, in this faded color, or this light color, the commuter cost, the passenger cost, you can say.

So, if you compare with the air, air journey, so air journey is twice slower. Like, if you take one hour by air, within half an hour you can reach by the Hyperloop. So, that means twice it is more fast in case of Hyperloop, and four times higher than Hyperloop in terms of cost. So, air is costly, air journey is costly. It is one-fourth, means if you spend like 100 units of cost, then only 25 units are needed for the Hyperloop, you can say.

Similarly, if we compare with the rail, basically the time is much more advantageous in case of Hyperloop because this is like nine times slower railways, railways journey is nine times slower than the Hyperloop. But cost is almost similar, you can say. But at least Time is money as you know. So, if you are saving time, you are saving lot of money in, in that, in that sense. Similar thing happens with the bus, it is nine times slower than the Hyperloop, and cost is around similar. And if you compare with the car, then seven times slower than the Hyperloop car journey and five times costlier than the Hyperloop. So, it is kind of very clear cut case that Hyperloop, once it is there in place properly, then it saves a lot of time, it says, it saves a lot of cost also.

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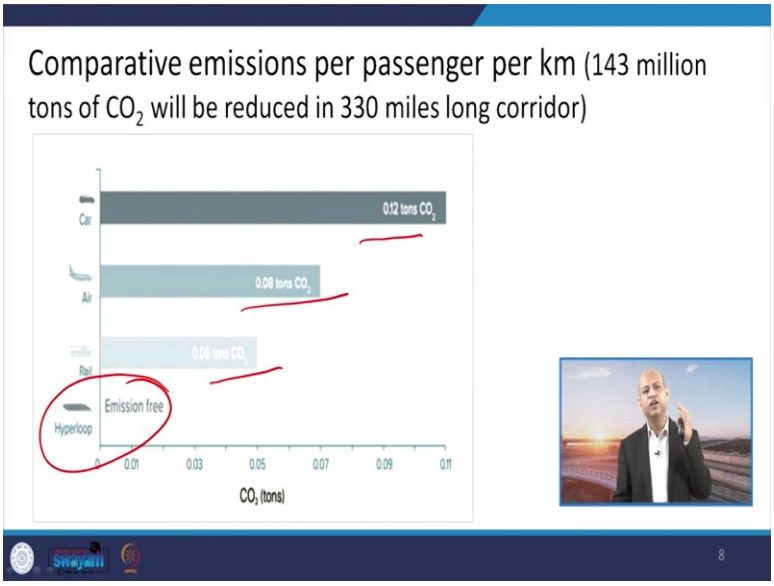

Well, when we compare about, like, emissions, whenever we talk about sustainability, the emissions of greenhouse gases or air pollutions, they are very important part of discussion. So, when we compare the emissions per passenger per kilometer, this picture gives in comparison to the Hyperloop because Hyperloop is emission free like electric cars. This is, there is no exhaust emissions, basically. So, no emissions are there.

Of course, electricity generation may be responsible for some emissions, but if we go towards like these, these power from renewable sources, then it is a clear winning case. But if you compare with the car like, point, 0.12 tons of the CO 2, in that particular per passenger per car, air is around 0.08, and the rail is 0.06, but Hyperloop is emission free.

And that way this is the, this is taken from a case, and in that case like 330 miles corridor is there. So, if we go for the Hyperloop in that particular corridor 143 million tons of the CO 2 will be reduced by applying this Hyperloop technology.

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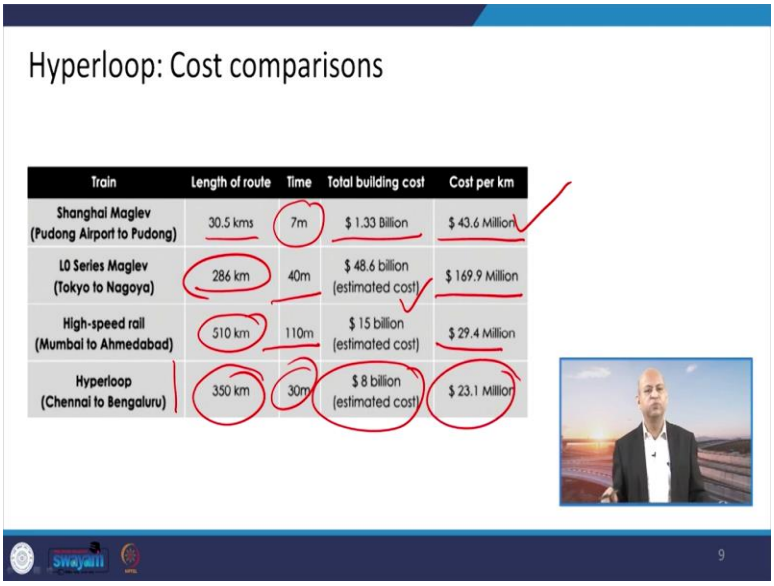

Well, the cost comparisons are also here. You can see like, very real life experiences, like Shanghai, this Maglev Pudong, airport to Pudong, this is 30.5 kilometer long stretch, and time taken is around seven minutes. The total building cost of this particular transportation system was 1.33 billion dollars, and the cost per kilometer is like 43.6 million. It is very costly, you can say.

But more than that, if you compare Tokyo to Nagoya, this L0 series maglev, so 286-kilometer stretch is there and it takes around 40 minutes. And the total building cost, means the investment was 48.6 billion, estimated cost, and per kilometer it was around 170 million, you can say.

High speed rail, Mumbai to Ahemdabad, which is under construction, this cost, around 510 kilometer, it will take 110 minutes, estimated cost is 15 billion, and 29.4 million per kilometer, this costs. So, it is cheaper than this Shanghai Maglev as well as much cheaper than this L0 series maglev.

Hyperloop, if we compare, one, this estimated cost for Chennai to Bengaluru, so 350-kilometer stretch is there, it will take only 30 minutes. Very, very fast. And 8 billion will be the total estimated cost and 23.1 million per kilometer cost will be opening. So, this is the cheapest option, you can say.

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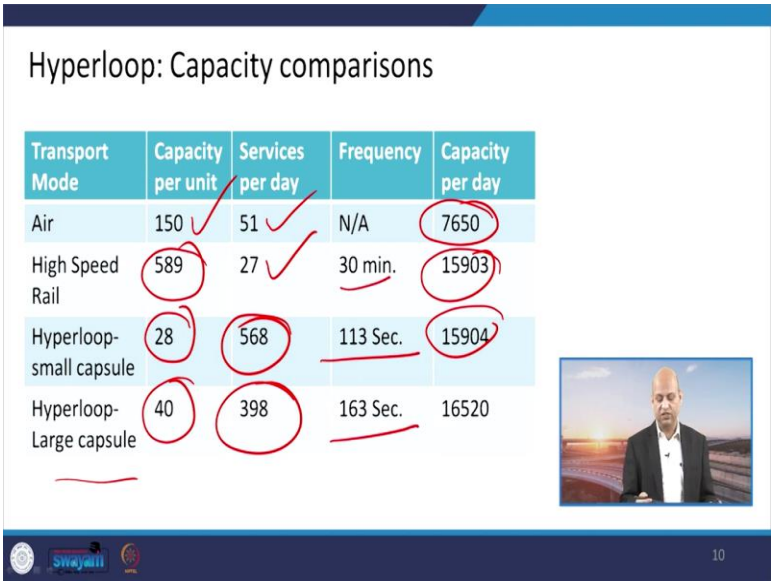

Well, the capacity compression, if we talk about, then the air capacity per unit, around 150 passengers, average, means you can have larger planes also, and the 51 services per day, and total capacity per day is around 7,650. High speed rail, of course, it is much more total capacity, but the services are less and capacity is more because railways, many more wagons are there.

Hyperloop is small capsule, and large capsule, two options may be there. A smaller one, 28 persons per unit and larger than 40. The total per day capacity because of very high frequency, you can see, very high frequency, and the time only 113 second, 163 second, you can compare like, 30 minutes, in comparison to that it is much more, then 16,520 per day, the capacity of the passengers which can be serviced. So, means from the cost point of view, from the capacity point of view Hyperloop is something which should be welcome.

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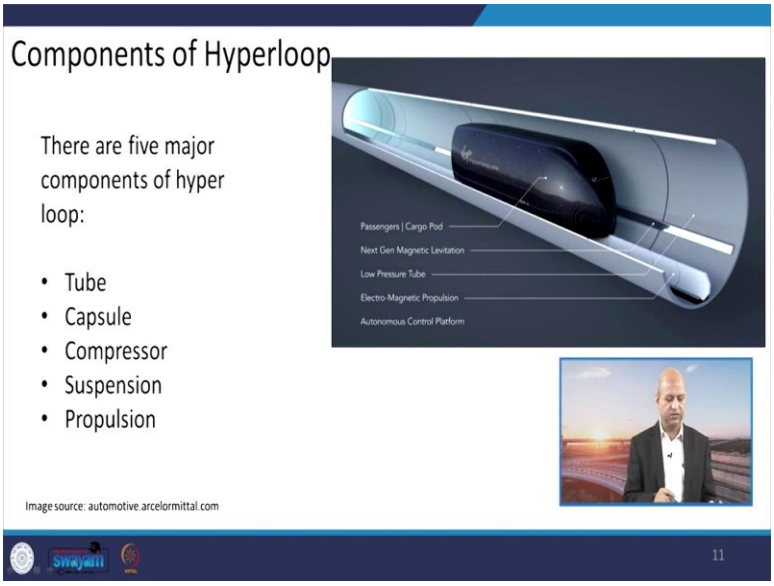

When we talk about components of the Hyperloop, the major components, so you can see like one is tube, the outer tube, or the pipe, big pipe, and then the capsule, that is, the pod which will carry the passengers, then the compressor is there for air movements, suspension system is there, and the propulsion to force it to move in the linear direction.

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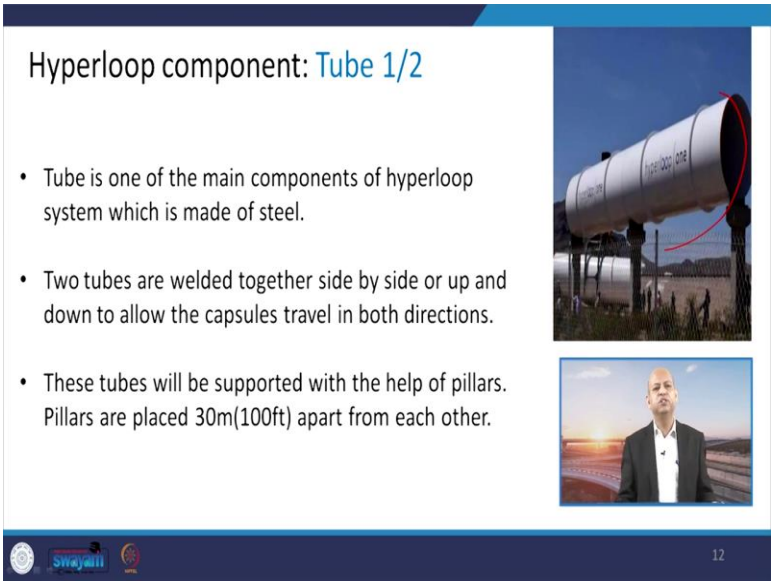

And then you talk about, like tube, then this is the main component of the Hyperloop system, which is made of the steel. So, you can see this is the tube, it is larger cross section. And then that two tubes are placed either side by side or one above one over, so that one tube is dedicated

from one direction, movement of the these capsules, and other for, like one going another coming. So, dedicated tubes may be there. Then these tubes will be supported by pillars, with the help of pillars and those pillars are placed around 30 meters apart from each other.

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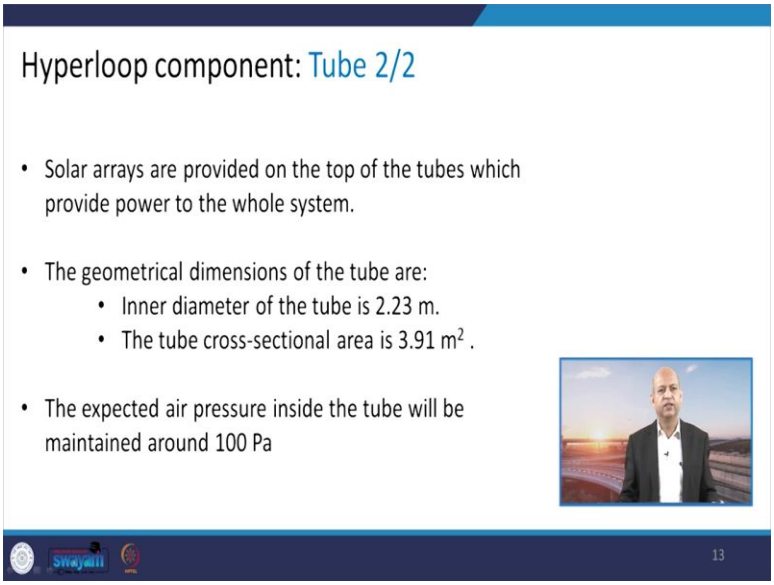

When we talk about like other systems or other components of the Hyperloop, then solar arrays are to be provided at the top of the tubes so that continuously it can harness the solar energy. Of course, there will be alternative sources of power also. It is not completely dependent on solar, but a lot of solar energy will be used whenever sunshine is there. Then the geometric dimension, you can see, the inner diameter of the tube, that big pipe is 2.23 meters, it is a larger size. And the tube cross section is around 3.91 square meter. And then the expected air pressure inside the tube will be maintained around 100 Pascal. So, those are the things, or parameters, very simple parameters, which are the part of the design things of the Hyperloop.

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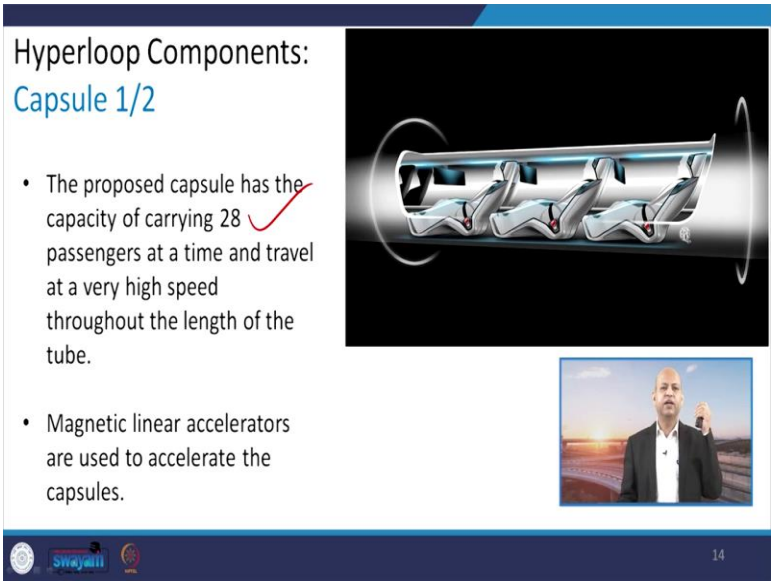

And when we continue about these Hyperloop components, so this capsule, which has the 28 carrying capacity, 28 passengers, this is the smaller one, the larger one has 40. So, the 28 passengers set a time, and it can travel at very high speed throughout the length of the tube. And then magnetic linear acceleration are used to accelerate the capsules. So, lot of new way of this transportation in terms of magnetic, magnetic forces et cetera.

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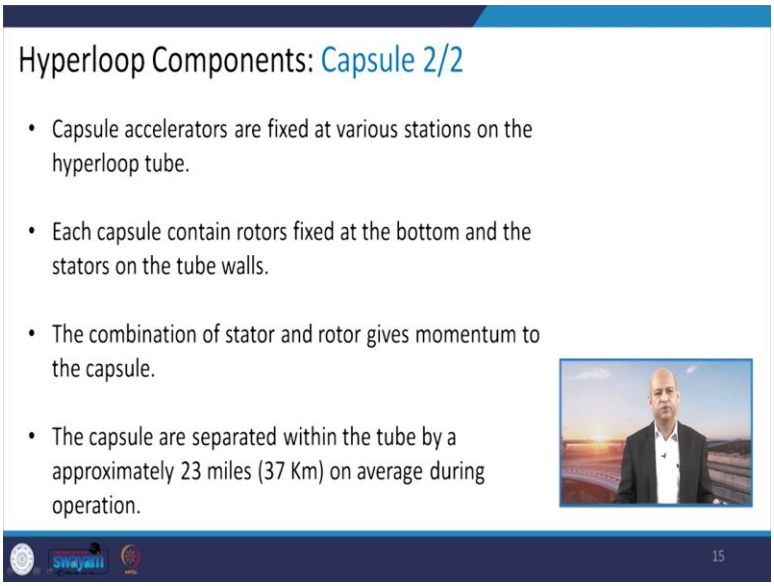

When we talk about acceleration, so the capsules, accelerators are fixed at various stations on the Hyperloop, so that the uniformity can be maintained. And then each capsule contains rotors fixed

at the bottom and these stators on the tube walls so that it can be used for this combination, this combination of stator and rotor. It gives the momentum to the capsule. So, acceleration and deceleration all these are controlled by this mechanism. And the capsules are separated within the tube by approximate distance of around 37 kilometer, so that safety issues can be operated very comfortably. And then this is during the operation. So, this is the minimum distance which is to be kept within two capsules, you can say.

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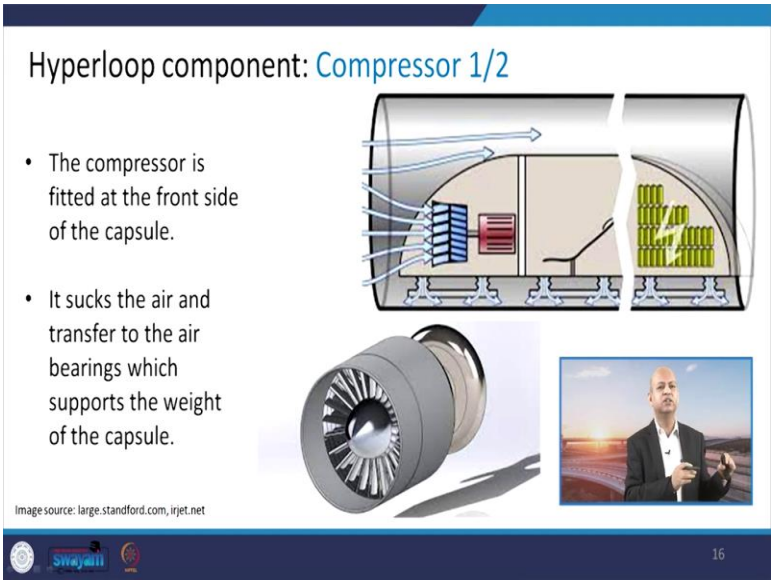

When we talk about further, like the compressor, so compressor is fitted at the front side of the capsule so that it can suck the air from the front side and it transfers the air to air bearings which supports the weight of the capsule, like cushion, or you can image in that way.

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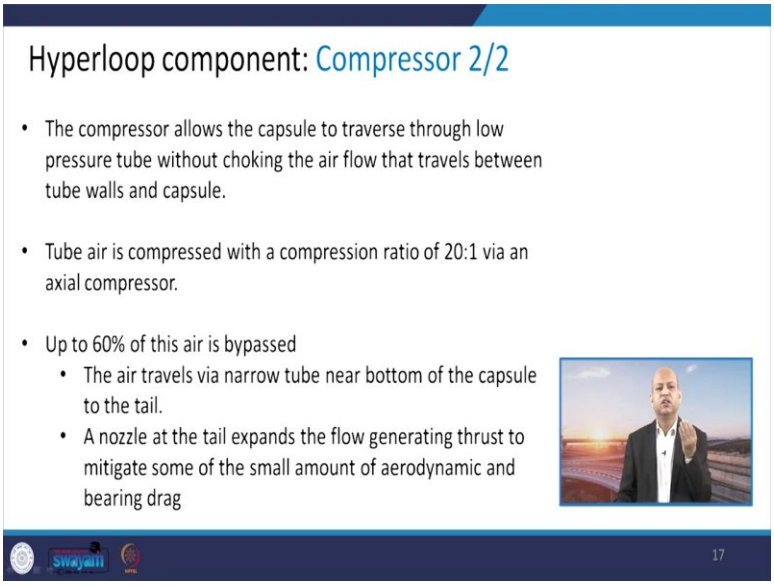

Well, then this compression allows the capsule to travel through low pressure tube without choking the airflow. So, that is very important. And then it travels between tube and the capsule, that air, so that the choking is not there, otherwise, a problem may arise. Tube air is compressed with a compression of ratio of 20 to 1 via this axial compressor and up to 60 % of this year is bypassed. So, the air which travels via a narrow tube near the bottom of the capsule to the tail and a nozzle at the tail expands the flow generating this thrust and this is used for the mitigating some of the small amount of aerodynamics and bearing drag. So, that, those kind of dragging forces, drag forces can be compensated.

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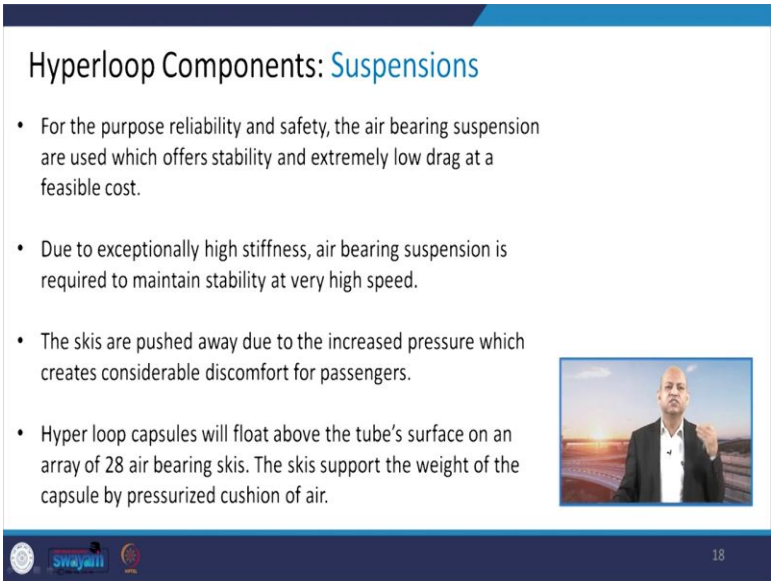

And then the suspension system, the suspension system is also very important. So, for that purpose, the reliability and safety is most important issues, and the air bearing suspensions are used which offers stability, and extremely low drag at a feasible cost. So, that is one important design aspect. Due to exceptionally high stiffness, here bearing suspension is required to maintain stability at very high speed.

Then there are some other components like skis, which are pushed away due to the increased pressure, which creates considerable discomfort for passengers. And the Hyperloop or capsules will float above the tube surface on an area of 28 air bearing skis. The skis support the weight of the capsule by pressurized cushion of the air. So, that kind of, very sophisticated design are ensured for suspension purpose.

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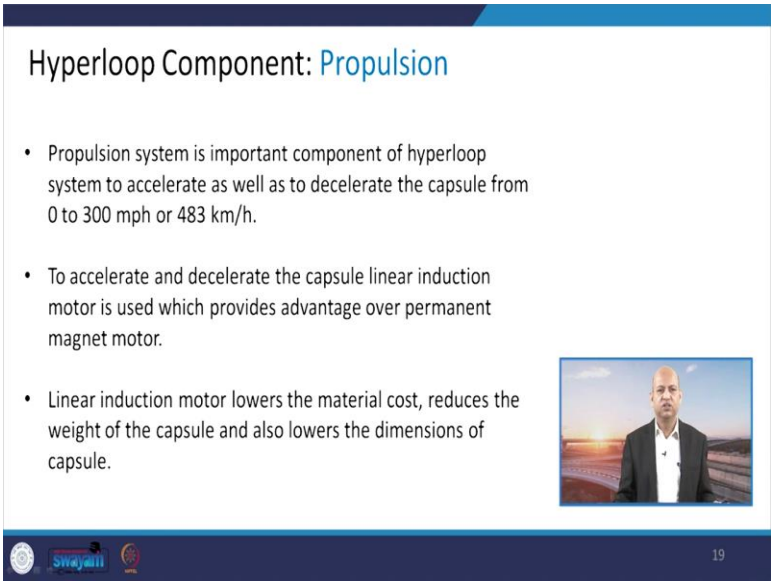

Similarly, for propulsion purpose there are mechanism like, this propulsion system is important component and it is required for acceleration and for deceleration of the capsule, from 0 to 300 kilometer, 300 miles per hour or 483 kilometer per hour, that kind of very high speed. And to accelerate and decelerate the capsule linear reduction motor is used, which provides advantage over permanent magnet motor.

Similarly, the linear induction motor lowers the material cost. So, these are the additional advantages and it reduces the weight of the capsule and also lowers the dimension of the capsule. So, in design these are very important features which takes place when we consider the complete design of the Hyperloop system.

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Well, when we talk about means, how many countries are there or where these Hyperloop related companies are operating or some testing facilities exist, and major studies are being conducted, so like in USA there are many, in Europe also. And then you can see in India also there are these companies and studies are there.

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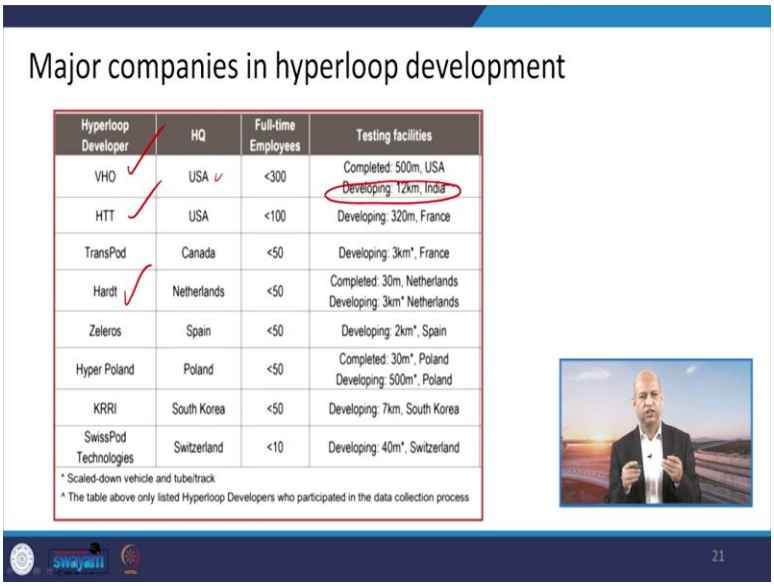

Hyperloop Developer	HQ	Full-time Employees	Testing facilities
VHO	USA	<300	Completed: 500m, USA Developing: 12km, India
HTT	USA	<100	Developing: 320m, France
TransPod	Canada	<50	Developing: 3km*, France
Hardt	Netherlands	<50	Completed: 30m, Netherlands Developing: 3km* Netherlands
Zeleros	Spain	<50	Developing: 2km*, Spain
Hyper Poland	Poland	<50	Completed: 30m*, Poland Developing: 500m*, Poland
KRRI	South Korea	<50	Developing: 7km, South Korea
SwissPod Technologies	Switzerland	<10	Developing: 40m*, Switzerland

* Scaled-down vehicle and tube/track

^ The table above only listed Hyperloop Developers who participated in the data collection process

Well major companies which are kind of leading companies in Hyperloop development, these are like VHO, HTT, TransPod, and their headquarters are given. Like these are in USA, in

Canada TransPod is there, and Netherlands, this Hardt, and Spain Ze, Zeleros, and Poland Hyper Poland, those kind of companies and countries are given.

Full time employees, number of employees are given, and then the testing facilities under these companies, what is the stretch size, all those like 12 kilometer in India, it is being developed by VSO, USA. So, those kind of figures or data are also given.

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When we talk about Hyperloop in India, so this is basically there are two planned, like one Virgin Hyperloop, project, the company, bridging companies in India and on the, this is on the Mumbai-Pune route. And then the another is possibly between Bangalore airport to the city. So, the state of Maharashtra has approved the Virgin Hyperloop, DP World Consortium, these two companies of different countries, multinational companies, companies, are these. And the original project proponents for the Mumbai-Pune route are these, the conglomeration of these two big companies. And this has been declared as the public infrastructure exercise for kind of a case study if it is very much successful then it can be multiplied in other stretches of India.

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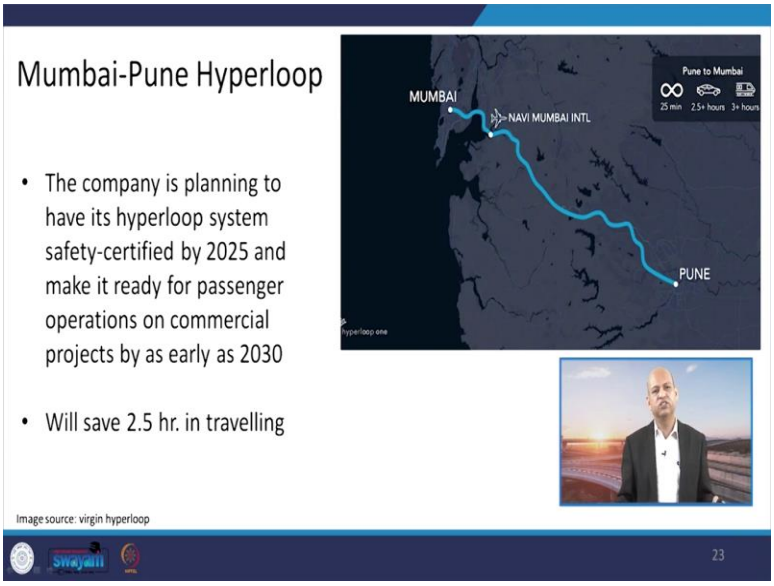

So, you can see from Mumbai to Pune, this is the kind of path for this Mumbai-Pune Hyperloop, and this company is planning to have this Hyperloop system CERTI, the safety certified by 2025, and it will be ready for passenger operations and like, a commercial project in early 2030. And it will save around 2.5 hours in traveling. So, 2.5 hours in modern era is a significant time span.

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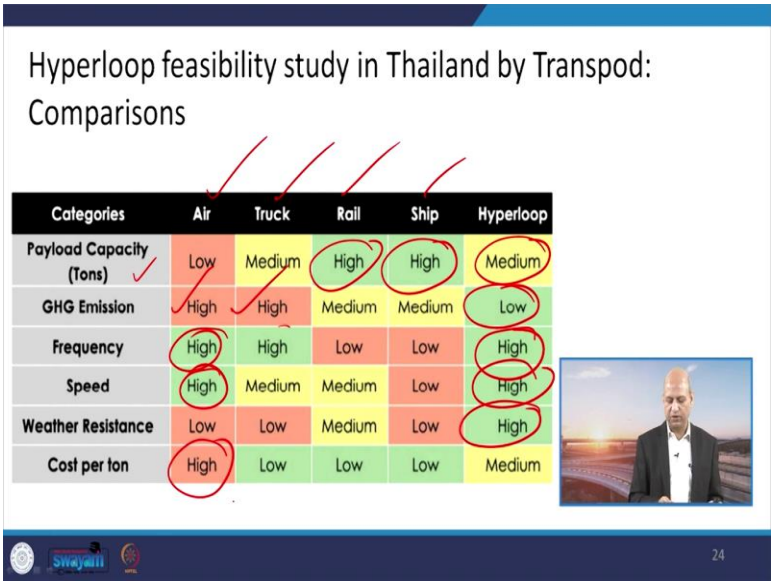

When we compare these feasibility of Hyperloop, these feasibility studies in Thailand, then there are comparison with different kinds of aspects, or features like capacity, and you compare it with other modes of transport like air, truck, rail, ship, and then Hyperloop. So, when we talk about

payload capacity, the air is very low in comparison, but Hyperloop is medium. Of course, rail has a lot of capacity and sip also has very high capacity, but truck medium. So, the Hyperloop compared in the truck in that, in that sense.

Greenhouse gas emissions, very high in case of air traffic and the truck mode, and medium in this ship and the rail, but it is very low in case of Hyperloop. That is only related to energy generation or power generation if we are, depending upon these fossil fuel related power plants. Otherwise, this is bare minimum if we go for like renewable resources.

Frequency, high, high and it is high in case of Hyperloop also, but in case of rail and ship, is not so. It is low, rather. Speed, like, it is high in case of air journey and Hyperloop it is also very high. Other modes of transport like trucks, rail and ship, they are like medium or low. Weather resistance, Hyperloop is very high weather resistance because it is under the tube so no flooding, nothing those kind of things are there. Whereas in case of rail and like air traffic also, affected by like bad weather also. Cost per ton, it is very high in case of air journey, but it is low in case of truck and it is medium in case of Hyperloop. But in totality if you go for the total things, you will see other things also.

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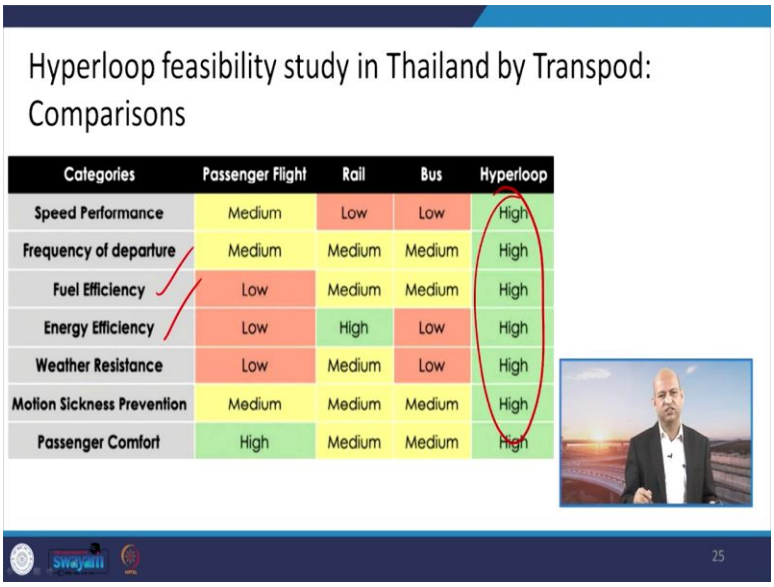

So, like if you see the performance, speed performance, frequency of departure, fuel efficiency, energy efficiency, weather resistance, then it is very high in that sense in comparison to other modes of the transport. So, means the totality, in totality the Hyperloop is much more attractive, you can say.

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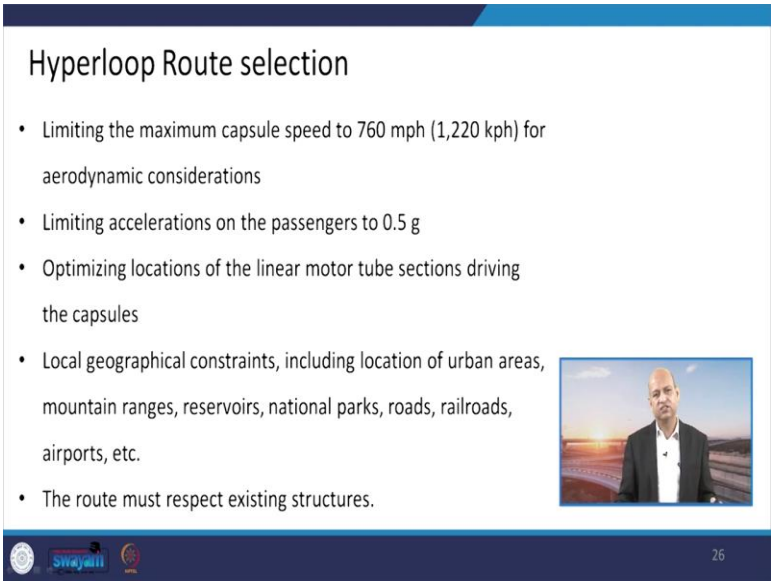

And when we talk about the route selection, so there are certain aspects or important features which has to be given good consideration, like limiting the maximum capsule speed. It can be up to only turn 1,220 kilometer per hour. Beyond that it will be difficult because of aerodynamic consideration. So, it should not exceed from that. But this is big, very large speed in fact, if you compare with existing modes of transportation, including air journey.

Then there are limiting accelerations on the passenger to around 0.5 this G, otherwise uncomfortable, this comfort level will be very low. Then optimizing locations of the linear motor, the sections driving the capsule, so that optimization has to be reached. Local geographical constraints are there, like, in urban areas or mountain ranges, reservoirs or national parks or roads, railroads airports et cetera. So, how to integrate with them because it takes the simple straight route then it is good otherwise, it is difficult. And the route must respect existing structure. So, that is one more aspect which to be taken into account.

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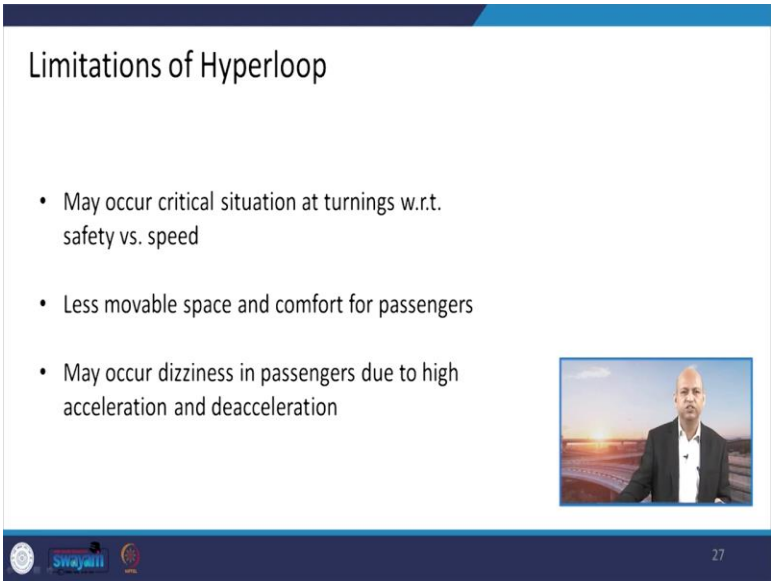

But there are some limitations of the Hyperloop. Like, it can occur, like, critical situation at turning with respect to the safety and the speed. So, turning should be very minimum and it should not be very sharp turns. So, the design of the route has to be taken very, in a sensitive way so that turning can be avoided. Only the straight routes can be designed.

Less movable space and comfort of the passengers, the comfort level in comparison to other modes of transport like railway et cetera, it will be less at present, in present context of the design. Then it is, it can result into like some health issues like dizziness in passengers just because of very high acceleration and deceleration. So, it can affect the health issues also. So, those are the limitations. Maybe some technological interventions can be implemented to reduce these limitations.

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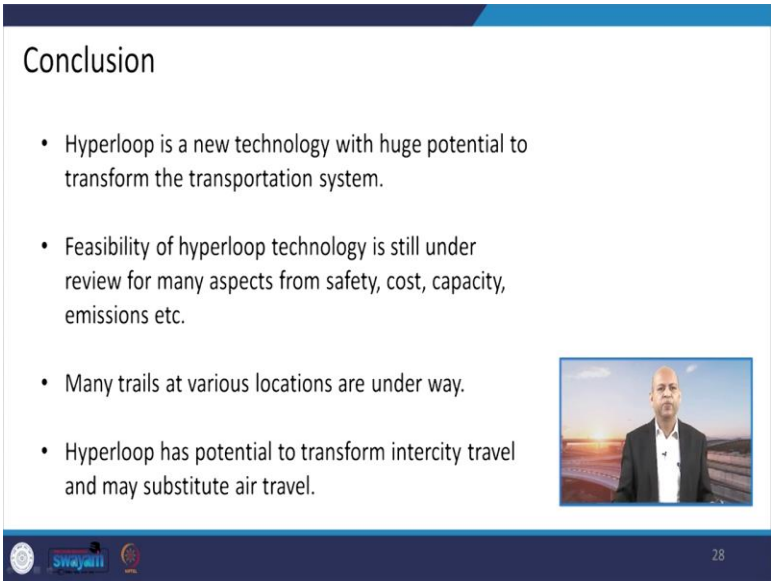

So, in conclusion, we can say that this Hyperloop is a new technology, very emerging technology, but it has huge potential to transform the transportation system from the existing to the new system. And the feasibility of Hyperloop technologies is still under review, at many, for many aspects like safety, cost, capacity, emissions or route related things.

And then many trails are, are they are like at various locations, some stretches are being tried. So, data will be available after some time. Then this Hyperloop has potential to transform this intercity travel, and it can also substitute the air travel. It will save a lot of time and cost also. Also, it will be very environment friendly.

So, we can say that this is the very upcoming and very welcoming technology. And maybe after a decade or so it can be very popular mode of transportation. And I hope that many of you can think in that way, in out of box thinking or creativity and you can also come up with some new ideas of the transportation.

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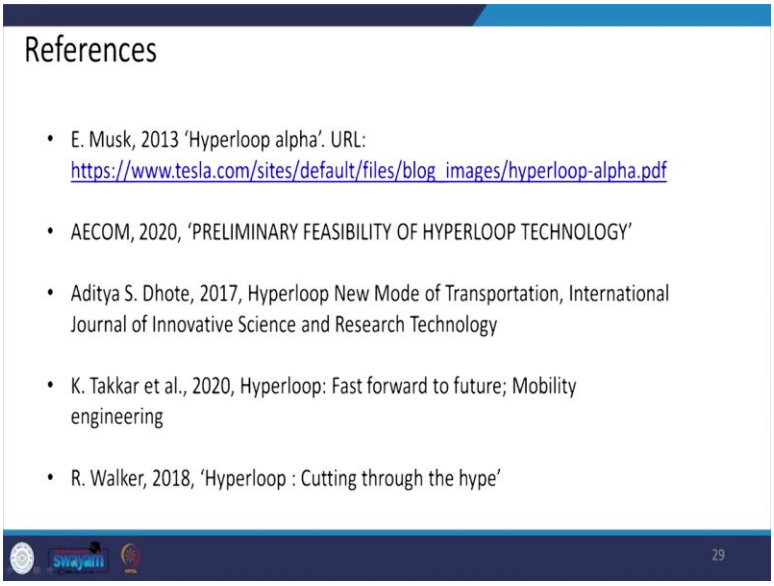

These are the references. You can go through to get additional information. And this is all for today. So, thank you for your attention. See you again. Thanks a lot.