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# A study on the contemporary propulsion techniques based on their applications on the Earth – A Review

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**Abstract: A detailed study comparing the propulsion technologies which are in used in transportation sector on earth is presented in this paper. Propulsion technologies can't be assessed only by its efficiency, which are usually calculated during the technology is invented. The technology needs to be assessed on how it proves its feasibility in real life application and simultaneously how it affects the nature and environment. The study is done by using various aspects such as energy efficiency, GHGs emissions, dependency on foreign oil, maintenance , health hazards, etc. Suitable data is provided to compare these aspects for various propulsion technologies in operation. This paper concludes by providing answer to the question, " Which is the most promising propulsion technology of the future on earth?"**

**Keywords: Comparison of propulsion technologies, Transport modes, Greenhouse Gas emissions, Health Hazards.**

## I. INTRODUCTION

Propulsion means the action of moving something by some force. The word is derived from two Latin words: pro meaning before or forwards and pellere meaning to drive [1]. Propulsion means to push forward or drive an object forward. A propulsion system is a machine that produces thrust to push an object forward [1]. The propulsion systems are incorporated into the vehicles and provide motion to them and these vehicles are used as a means of transportation by the humans.

The transportation system is an important aspect of everyone's life. According to a study done by the Harvard Health Watch, an average American spends 101 minutes per day driving [2]. That means that in a lifetime, an average American spends 37,935 hours driving a car (assuming that he/she starts driving at 17 and drives until 78.7 years old) [2]. In that time, that person will drive around 798,000 miles (1,284,256 kilometres), which is approximately the distance it takes to drive to the moon more than three times [2]. Considering other modes of transportation too i.e. bus, train, aeroplane, etc., will add a lot more. So a person travels a whole lot of his/her lifetime while using different modes of transportation and so a consumer's expenditure on transportation in his lifetime would also be much of his lifetime earnings. According to the survey by the Department of Labour, U.S.A in 2014, total annual expenditure by an average American consumer is $53495 out of which around 17% is spent in transportation [3]. This data represents that level of importance of transportation in everyone's life.

Highways and air transport have eased the transportation for so many people across the world collaboratively, whether its for business or for pleasure, and consequently improved their quality of life. But the population growth seems to stress the traditional systems. Congestion on highways and at airports, not only wastes time and increases fuel consumption, but also constrains mobility to the extent that economic growth and productivity are adversely affected [4]. One of the many concerns at present is the rising costs. Environmental issues associated with building and operating air and highway systems (such as air and noise pollution) have become a major problem in expansion [4]. In addition to them, there is also increasing oil dependency of developed countries. Present transportation sector is mostly petroleum oriented, accounting for 64 percent of total petroleum use. Without more efficient or renewable alternatives for transportation, the oil dependency would reach new heights.

Nowadays environmental impact of these technologies has become a major concern. Transport is a major use of energy, and burns most of the world's petroleum. Transportation accounts for two-thirds of all U.S. petroleum consumption [5]. The transportation sector is majorly responsible for producing CO, $NO_X$, PM, etc. which causes air pollution and have serious health hazards. Developed countries are trying to reduce air pollution by imposing certain regulations but they are not much of help as the number of vehicles are continuously increasing. Other environmental impacts of transport systems include traffic congestion and automobile-oriented urban sprawl, which can consume natural habitat and agricultural lands [5].

What people seek today is cheaper, faster, efficient and cleaner technology for transportation. So, what could be the most promising propulsion technology of the future for transportation on earth?

## II. COMPARISON OF SEVERAL TECHNOLOGIES BASED ON PRESENT APPLICATIONS

There are many factors which can help to compare several technologies used for transportation at present. Some of them are:

### FRICTION

Rolling friction is the force which resists the motion of a body when the body rolls on a surface. It is a serious hurdle to overcome as it increases the fuel consumption of the vehicle. Autos, buses, conventional rails are propelled by the combustion engines and face both rolling drag as well as air drag, so their power efficiency is quite less. Moreover, the friction causes wear of the material which reduces the life of the tires and also increases the maintenance cost.

Maglev stands for Magnetically Levitated. Trains which are propelled by maglev technology do not need tires and so

 

doesn't have any physical contact with the track. That means they travel with zero friction. Due to the lack of physical contact between the track and the vehicle, maglev trains experience no rolling resistance, leaving only air resistance and electromagnetic drag, potentially improving power efficiency. That creates the potential for speeds faster than all the conventional rail travel used today. Coming to the airplanes, in which thrust is produced by jet engines. They also face only air drag but they consume a substantial amount of fuel so power efficiency decreases.

## ENERGY EFFICIENCY

All types of motorized transport use non-renewable energy and results in emission of pollutants, noise, accidents and congestion. It is generally accepted that all forms of public transport are more substantial than private transport and comparison between their efficiencies depends on the assumptions made on occupancy levels, whether the vehicles are actually operating at given levels of efficiencies, the speed of the vehicle, etc. Here in this graph the efficiency is compared of different modes of transportation based on different vehicle speeds.

Figure 1 shows the comparison of the energy efficiency by transport mode in barrels of oil or oil equivalent per 10,000 passenger miles.

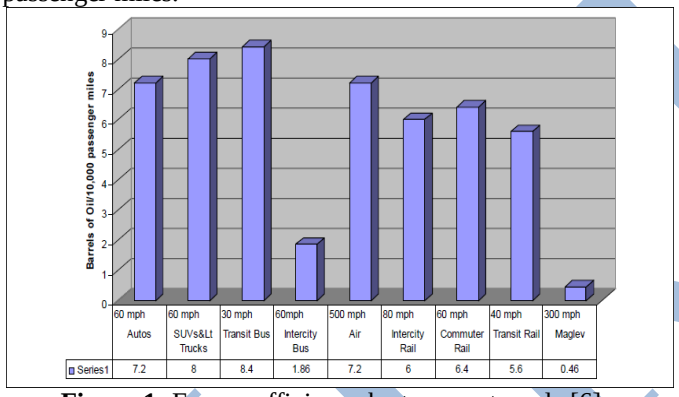


**Figure 1:** Energy efficiency by transport mode [6].

**Source:** Transportation Energy Data Book, 25th Ed. By Stacy Davis and Susan Dregel, Center for Transportation Analysis, Oak Ridge National Laboratory, ORNL-6874 (2006) [6].

One barrel of oil= 5861520000 J of energy,
One barrel of oil= 5861.52 MJ of energy.

| Mode of Transportation | Speed (mph) | Barrels of Oil per 10000 passenger mile | MJ per passenger mile |
|---|---|---|---|
| Autos | 60 | 7.2 | 4.22 |
| SUVs & Lt trucks | 60 | 8 | 4.689 |
| Transit Bus | 30 | 8.4 | 4.92 |
| Intercity Bus | 60 | 1.86 | 1.09 |
| Air | 500 | 7.2 | 4.22 |
| Intercity Rail | 80 | 6 | 3.52 |
| Commuter Rail | 60 | 6.4 | 3.75 |
| Transit Rail | 40 | 5.6 | 3.28 |
| Maglev | 300 | 0.46 | 0.269 |

**Table 1:** Energy efficiency by mode.

According to the table, for speeds equal to or less than 60 mph Intercity bus is the most efficient mode of transportation, for speeds greater than 60 mph Maglev is the most efficient mode of transportation. The most inefficient mode of transportation seems to be the transit bus here as it's not only slow but also consumes more barrels of oil per passenger mile than air transport. Energy consumption per passenger mile of autos, SUVs & Lt trucks are also quite high. If we take a look at maglev, at around 150mph, it would consume about only 2% of energy in comparison to a 60mph auto.

## DEPENDENCY ON FOREIGN OIL

In the United States 28% of energy consumption is only to transport goods and people. As the transport facilities have been made easily conceivable for general public, the transportation sector has increased rapidly. The transportation sector includes transportation used by people in everyday's life and the transportation of goods by road, rail, air or ship. Small personal vehicles, SUVs, Motorcycles, Buses come under the road transport vehicles. Trains, whether powered combustion engines or electricity, come under the rail transport. Commercial jet aircrafts, gliders, private jets and cargo planes come under the category of air transport. Transport by cargo ships or ferries or cruises is considered under the ship transport.

Freight transport is also considered under the air and ship transport. Over the past century, dependence on vehicles burning petroleum-based fuels has become a defining component of every person in the world, bringing countless benefits. The United States, with less than 5% of the world's population, alone have around 34% of the world's automobiles. Over the next 20 years, the total number of miles driven by Americans is projected to grow by 40%, increasing the demand for fuel [7].

The petroleum fuels used for transportation include gasoline, diesel fuel, jet fuel, residual fuel oil, and liquid petroleum gases. In 2014, those fuels provided 92% of the total energy used by the transportation sector in the United States [8]. Electricity provided less than 1% of the total energy used. Petroleum consumption in transportation sector was estimated to be around 14 million barrels per day by June 2014 [8].

One might think that airplanes, trains, and buses would consume most of the energy used in this sector but, in fact, their percentages are relatively small—about 7% for aircraft and about 3% for trains and buses. Light trucks, cars, and motorcycles use about 57% of the total amount of energy consumed for transportation in the United States. Large trucks use about 23% of the total amount of energy consumed for transportation, boats and ships use about 4%, and pipelines use about 3%. The military uses about 3% of the total amount of energy consumed for transportation.

| Use Type | Energy consumption |
|---|---|
| Light Trucks | 30% |
| Cars and Motorcycles | 27% |
| Other trucks | 23% |
| Aircraft | 7% |
| Boats and Ships | 4% |
| Trains and Buses | 3% |
| Military | 3% |
| Pipeline Fuel | 3% |
| Lubricants | <1% |

**Table 2:** Transportation Energy use by type [9].

 

**Source:** U.S. Energy Information Administration, Annual Energy Outlook 2015.

Coming to Maglev system, which runs on electricity which could be produced by oil or nuclear or hydro or solar power. Moreover, the maglev technology has higher energy efficiency at higher speeds which results in less energy consumption. The increasing population will result in increase in demand of oil, but we all know that the oil reserves are soon to get completely exhausted. So maglev may have a upper hand here as it is quite less dependent on oil. Increasing renewable technologies in producing electricity could reduce the oil consumption in generating electricity for general use. According to Maglev-2000 Project, Maglev-2000 will use approximately $0.0075 worth of power per passenger mile [6].

## GREENHOUSE GAS EMISSIONS

Transportation sector alone is responsible for 14 percent of global Greenhouse Gas (GHG) emissions, making it a major contributor to global climate change, which is equivalent to 18 percent of global $CO_2$ emissions and 24 percent of Carbon Dioxide ($CO_2$ ) emissions from energy-related sources. While the $CO_2$ produced during generating electricity used in transportation is only 0.3%.

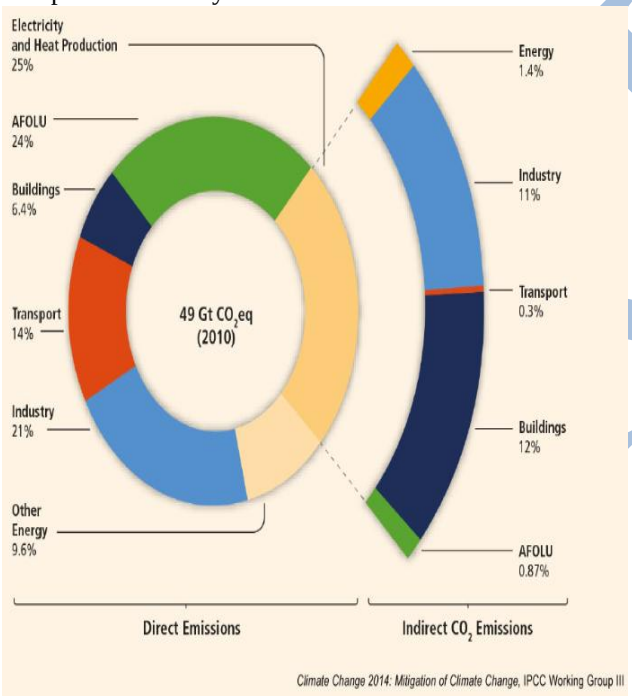


**Figure 2:** Global greenhouse emissions by economic sectors [10].

**Source:** Climate change 2014:Mitigation of climate change

Within the transportation sector, road transport, at 72 percent of the sector and 10 percent of global GHG emissions, accounts for the largest share. Air Transport, including both domestic and international, amounts to about 12 percent of transport emissions, and 2 percent of overall GHGs.

Transport emissions are expected to increase by about 40% in about two decades. With respect to energy sources, transport is dominated by oil, which amounts to 96 percent of energy supply and 97 percent of emissions [11].

The transportation sector accounts for fully 32 percent of U.S. carbon dioxide emissions. Americans drive 1.5 trillion miles per year in automobiles alone, and an additional 600 billion miles in personal trucks and SUVs [11]. Automobiles and light trucks combined consume 115 billion gallons of gasoline and diesel fuel per year, emitting 19.8 percent of total U.S. carbon dioxide emissions [11].

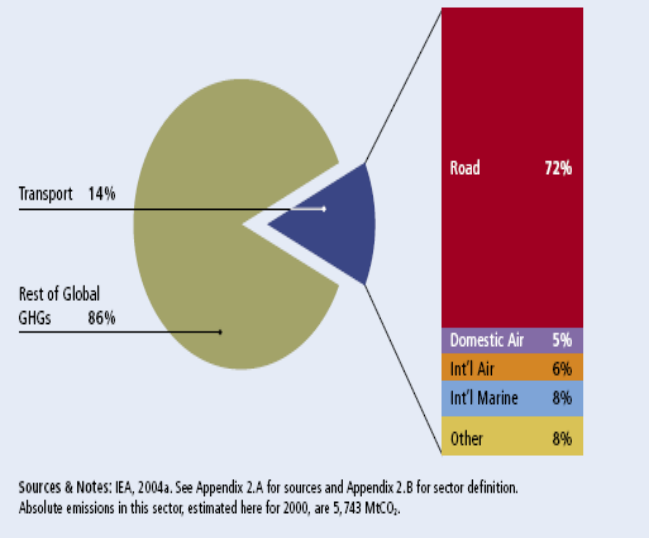


**Figure 3:** GHGs from Transportation

**Source:** World Resources Institute Report "Navigating the Numbers: Greenhouse Gas Data and International Climate Policy", 2005 [11].

Source: Individual Opportunities to Cool Global warming, 2006 and UK Ultrasound Fact book, October, 2006 [11].

| Mode | BTU/Passenger mile (BTU) | $CO_2$/Passenger mile (lbs) |
|---|---|---|
| Commercial Aircraft-domestic | 4053 | 0.647 |
| Automobile (Avg 1.59 persons) | 3635 | 0.569 |
| Transit Bus | 4802 | 0.775 |
| Commuter Rail | 2932 | 0.473 |
| Maglev | 1800 | 0.117 |
| High Speed Rail | 2500 | 0.174 |

**Table 3:** Transportation Mode and Energy Consumption and Carbon Dioxide Emissions [11].

Maglev vehicles emit no pollution. When they consume electricity no carbon dioxide is emitted. Even if they use electricity from coal or natural gas fired power plants, the resulting $CO_2$ emissions is much less than that from cars, bus or airplanes because of maglev's very high energy efficiency.

## TRAVEL COST AND TRAVEL TIME

According to the Bureau of Economic Analysis, Americans spent $988.2 billion on driving (personal vehicle) in 2005 [12]. This includes capital cost, complete operating cost (including fuel cost and infrequent maintenance), taxes, but not highway subsidies. According to the Federal Highway Administration, Americans drove 2.99 trillion vehicle miles in 2005[12]. Counting only passenger vehicles, and not heavy trucks, and it was 2.75 trillion vehicle miles. According to the US DOT, the average auto carries 1.63 people, so 2.75 trillion vehicle miles equal 4.48 trillion passenger miles [12]. Total cost of travel when divided by total miles travelled gives the average cost of driving per passenger mile, which come out to be around 22 cents.

According to cells Q1371 through S1378 of the spreadsheet, average capital and operating costs per passenger mile of bus is 0.14 and 0.78 cents respectively, while for commuter rail are 0.26 and 0.39 cents respectively [12]. Capital costs of

 

driving should not be considered for any given year as the person who owns the vehicle use it for many years, so capital costs must be spread throughout over roughly 30 years worth of passenger miles. The average cost for air travel is about 13 cents per passenger mile [13]. This includes labour, airplane fuel, and other costs, and corresponds to a ticket price of about $600 round trip, for a coast-to-coast flight. But as we know that most airports are outside the city because of the space needed, so the cost of going to the airport should also be considered while comparing to the rail transport. Some tickets cost less, some more, for a particular flight, depending on the discount offer, date of purchase, age, and so on. The 13 cents per passenger mile does not include government subsidies for airports, highway access, FAA operations, etc [13].

M-2000 Maglev operational costs for vehicles, energy, and labour total about 4 cents per passenger mile, but this projection does not consider the amortization cost of the guide way because it is really difficult to assess the amortization cost. Amortization cost depends on whether the maglev is going to carry only passengers or freight cargo, or both in one go. For a M-2000 guide way cost of 10 million dollars per 2-way mile, that carries only passengers, amortization cost is about 10 cents per passenger mile, assuming a 30-year payback period and 10,000 passengers daily [13]. If the guide way carries 1000 trailers daily and allocates 3 cents per ton mile (30 tons per trailer) of revenue to guide way amortization, the passenger share for guide way amortization is zero cents per passenger mile. Total cost for passengers is then only 4 cents per passenger mile, about 1/3 of that for air travel, so the travel cost completely depends upon project application, means how they are going to use the transport [13].

Travel time would be much in case of a car, bus or conventional rail than aeroplane and maglev. Although jet aircraft speed is greater than Maglev (500 mph compared to 300 mph) the actual trip time will be much less for Maglev. The total travel time includes the time to get to the station, time to reach from one place to another and time to check out from the station too. The airports are mostly out of the city, while Maglev stations would be much closer to the residential areas, which would ultimately save time. The trains are much more frequent than aeroplanes in terms of departure, airports have few flights a day for the same destination and that is also not for most airports, while maglev stations would have much more train departures like normal trains do for the same destination. Maglev schedules will not be hindered by bad weather problems which is often the case for air travel [13].

## MAINTENANCE

Cars and buses are powered by the internal combustion engines and these engines need maintenance at regular time intervals. Due to the high temperature and pressures inside the engine cylinders wear and tear starts which reduces the life of the engine. Maintenance at regular intervals can help to extend the life of engine. Wear in tire also deteriorates it slowly. Need of such type of maintenance means maintenance cost is high.

Trains could be powered by combustion engines or electricity. Higher the speed of train, more the abrasion and hence lesser the life of the material. And least expenditure on maintenance is what everyone desires. Low maintenance costs make an essential contribution to economical mobility. Likewise, aeroplanes also require intensive maintenance for their engines and the cost of maintenance is very high in case of aircrafts.

For maglev, which is most of the time at levitated position, even at the highest speeds, and do not make contact with their guideways, low maintenance costs are typical. Maglev systems are practically frictionless(rolling) in operation and therefore offer relatively low expenditures for maintenance. Maglev vehicles are designed for operating speeds up to 500 km/h. Because there is no mechanical contact and wear, Maglev guideways could last up to 50 years or more with very little maintenance at all [14]. This implies that maglev will have much longer lifetime, moreover longer lifetime with less maintenance expenditure. Generally, for automobiles or aircrafts, maintenance expense increases with the time for which it is in service.

## HEALTH HAZARDS

As mentioned in 2.4, Transport account for the 14% of global GHG emissions and 72% of it is from road transport which includes private vehicle (car, motorcycle, etc.) and 5% is from domestic aircrafts. Due to substantial increase in GHGs, global temperature of the earth is rising continuously which is the main cause of the melting of ice glaciers. Scientists have been emphasizing on this matter for a long time, they have urged to take some serious action on this matter. Environmental impacts of these technologies are not just limited to this, there are several gases which come out of the exhaust of the internal combustion engines are really dangerous for health. Various health problems related to exhaust gases are:

The five major air pollutant species which comprise the most significant emissions from road vehicles and commercial jet aircraft are volatile organic compounds (VOCs), carbon monoxide (CO), oxides of nitrogen (NOx), particulates (PM), and sulphur dioxide (SO2). The above stated pollutants could have serious health effects. Some of them could be poisonous in their original form while some become poisonous by transforming into another compound, after they had reacted to some specific compounds. NO and $NO_2$ after reacting with ammonia, moisture and other compounds forms vapours of nitric acid, which if inhaled, may cause respiratory diseases. In a 2005 U.S. EPA study the largest emissions of NOx came from on road motor vehicles, with the second largest contributor being non-road equipment which is mostly gasoline and diesel stations [15]. CO is highly poisonous, but it is colourless, odourless and tasteless which makes it difficult to detect it. It is the result of combustion in insufficient oxygen. It reduces the ability of haemoglobin to carry blood to body tissues by forming carboxyhemoglobin. In 2011, 52% of carbon monoxide emissions were created by mobile vehicles in the U.S [15]. Particulate matter include particles of liquid or solid in air, which are highly hazardous as these are way too small. These are classified as PM10 (about 10µm (micrometers) in diameter, PM2.5 and PM1. Health effects include asthma, lung cancer, cardiovascular issues, respiratory diseases, birth defects, and premature death. A 2011 UK study estimates 90 deaths per year due to passenger vehicle PM [15]. In a 2006 publication, the U.S. Federal Highway Administration (FHWA) state that in 2002 about 1 per-cent of all $PM_{10}$ and 2 per-cent of all $PM_{2.5}$ emissions came from the exhaust of on-road motor vehicles (mostly from diesel engines) [15]. Volatile Organic

 

Compounds (VOCs) carbon-based chemicals that can evaporate at low temp(room temp). Some could be smelled but some could not. They could produce ozone which is the primary constituent of smog. Various health effects are eye irritation, headaches, dizziness, visual disorders. A 2005 U.S. EPA report gives road vehicles as the second largest source of VOCs in the U.S. at 26% and 19% are from non road equipment which is mostly gasoline and diesel stations [15].

Maglev do not emit any harmful gases while in operation. It is cleaner, the only thing is the emissions produced while producing electricity for its consumption. In Shanghai, expansion plans for the airport-connector maglev were put on hold after citizen protests in 2007 voiced concerns about maglev's perceived noise and magnetic-field emissions [16]. But this couldn't stop the superfast maglev as the magnetic field levels were proved to be well below the accepted standards, considering direct as well as alternating current profiles.

According to Maglev 2000 project, the magnetic fringe fields from the quadruple magnets on the M-2000 vehicles drop off much faster with distance than do the fringe fields from dipole magnets[13]. This rapid decrease in fringe fields allows the magnetic fields in the passenger compartment to be at Earth ambient level, ~ 0.5 Gauss, which we feel every time [13].

A typical profile for Transrapid that has been measured in the field is shown below.

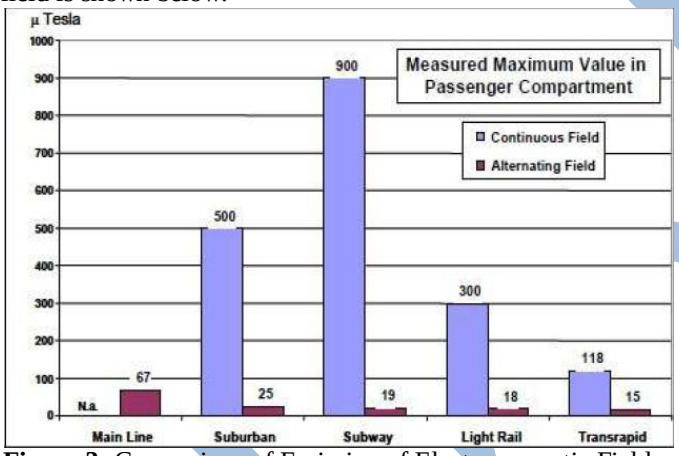


**Figure 3:** Comparison of Emission of Electromagnetic Fields [16].

**Source:** Dispelling the myths about Maglev.

The above figure shows that humans experience much more intense magnetic fields while travelling in subway or electric trains. Transrapid, German monorail train which uses maglev technology, seems to produce fields of less intensity than others according to above figure.

Noise pollution was also pointed out by the protestors during Shanghai expansion. Noise pollution is an important factor to consider but it does not the effect our lives in a way like CO, NO , PM do. It may not be poisonous but it could have a detrimental effect on the neighbourhood. It has a serious on the fauna of the society.

As there is no rolling contact between the track and the tires in maglev trains, there is no rolling and screeching noise. The only noise is due to the air drag, or aerodynamic noise. Maglev trains have high aerodynamic characteristics which makes it quieter than other trains at the same speed.


**Figure 4:** Comparison of Noise Emission [17].

**Source:** Floating Trains

The above figure shows that the transrapid at 200km/h produces less noise than ICE and TGV. It clearly implies that the noise emissions are also in certain standards of maglev.

## III. RESULT AND CONCLUSION

This paper has provided a comparative review of the current propulsion technologies. The comparison was based on the present applications of those technologies because technologies which seem feasible in the laboratory may or may not show feasibility of that degree in practical life. Now the question remains, What could be the most promising propulsion technology of the future for transportation on earth? The answer is Maglev technology. Maglev systems came out to be superior in almost every aspect discussed above. Rolling friction gets eliminated in maglev, which eventually gave us the opportunity to develop faster and faster trains. Energy efficiency of the maglev is higher than every other mode of transport, whether its road, air or conventional rail. It has the ability to reduce the dependency on foreign oil. In fact if we couple the renewable electricity generation with the Maglev, like Solar power, it would not only be able to generate power for its own operation it would surely light up at least a small town. It produces zero GHGs in operation, the only GHGs produced are during the power generation by burning coal in power plants, which could replaced by renewable energy. Least maintenance required, travel cost, travel time. Even it has no health hazards. The problems of which environmentalists have been screaming about from the past decade could be mitigated by this technology.

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