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Energy Efficiency and Economics of Maglev Transport

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Maglev 2000

Abstract

The energy efficiency and economics of Maglev, a new mode of transport, are analyzed. Maglev vehicles are magnetically levitated and propelled above a guideway without mechanical contact or friction. Speeds of 300 mph or more can be achieved, limited only by air drag. 1st generation passenger Maglev systems are already operating in Japan and China. The much lower cost, more capable 2nd generation Maglev-2000 system now under development can transport roll-on, roll-off highway trucks, freight containers, and personal autos in addition to passengers. Implemented as a 25,000 National Maglev Network in the U.S. it can, in combination with electric autos for local trips, eliminate oil imports, saving over 500 Billion dollars per year in purchases of foreign oil, greatly reducing the U.S. trade deficit. Maglev is very energy efficient. For example, 300 mph Maglev uses only 1/10th as much energy per passenger mile as a 60 mph 20 mpg auto. The cost of construction of the proposed National Maglev Network would be paid back in less than 5 years by transporting 3000 highway trucks per day (about 1/5th of the truck traffic on a typical Interstate highway) making it practical for private investment without requiring government funding and subsidies. Between cities, the high speed Maglev-2000 vehicles would travel on elevated monorail guideways. In urban/suburban regions, the Maglev vehicles would transition to existing RR trackage, on which thin low cost aluminum panels had been attached to the cross-ties, allowing the Maglev vehicles to travel levitated and be magnetically propelled.

Figure 1. Maglev-2000 Vehicle on Elevated Monorail Guideway

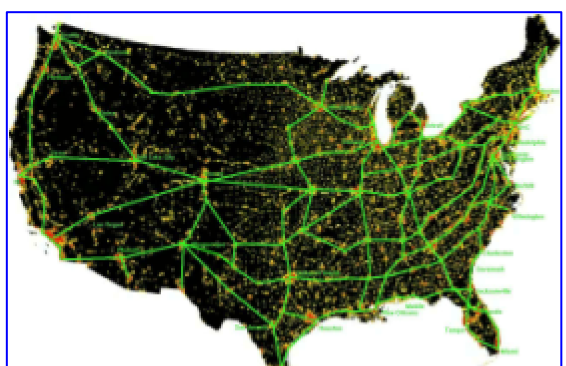


Figure 2. 25,000 Mile National Magev-2000 Network

Overview

The message:

- Oil fueled autos, trucks, airplanes and trains dominated 20th Century transport
- Electrically powered autos and Maglev will dominate 21st Century transport

The transition from oil fueled transport to electric transport is inevitable. Oil is running out and there are no acceptable substitutes. Global warming is seriously affecting our climate, our food supply, even our ability to survive.. Unless we can soon drastically reduce fossil fuel consumption, Earth will reach a tipping point from which it cannot recover. In a few decades, acidification of the ocean by absorption of the rapidly climbing carbon dioxide levels in the atmosphere will prevent marine organisms from forming their shells, destroying most of the life in the ocean.

A second tipping point is the runaway greenhouse effect from the release of carbon dioxide from the warming permafrost regions as their stored organic material decomposes. Even more troubling is the release of methane from the marginally stable methane hydrates in the sea beds as the ocean warms up. Methane is 20 times more effective as a greenhouse gas than carbon dioxide. There are 10,000 Billion tons of methane stored in Earth's sea beds – enough to turn the planet into a new Venus. Methane boils into the atmosphere have recently been observed in the Artic Ocean due to its warming.

Carbon dioxide emissions from transport are already a major factor in greenhouse gas releases. The average American auto emits 10 tons of carbon dioxide per year. The American transport sector emits over 10% of the 25 Billion tons of carbon dioxide per year in the World. As China, India, and other countries rapidly industrialize, the World's carbon dioxide transport emissions will by themselves soon approach today's total value of 25 Billion tons annually. Even worse, as oil supplies run out, it will be necessary to shift to coal as the supply source for synthetic fuel, much as Germany did during World War II. In that event, World carbon dioxide emissions from just transport will be double today's total. Rising at 4 parts per million annually, in just 25 years, atmospheric carbon dioxide concentration would be ~500 ppm, twice that before the industrial revolution.

1st generation electric autos and Maglev systems are already operating on a small scale. Much more capable and much lower cost 2nd generation electric auto and Maglev systems are in development and will be implemented within a few years.

Figure 1 shows a drawing of the proposed 2nd generation Maglev-2000 vehicles on an elevated monorail guideway. It is powered by electricity, not oil. 1st generation Japanese and German Maglev systems are now operating in Japan and China, carrying passengers. The Japanese 1st generation system, which is based on the 1966 invention of superconducting Maglev by Powell and Danby, has operated at speeds up to 361 mph.

Figure 1 Maglev 2000 Vehicle on Elevated

The 2nd generation Maglev-2000 systems, which is based on more recent inventions by Powell and Danby, is much cheaper and more capable than the present 1st generation Maglev systems. The M-2000 systems in addition to passengers, can transport Roll-on, Roll-off highway trucks, freight containers, and personal autos.

Because of its low construction cost and large revenue potential from carrying highway trucks, the payback time for a Maglev-2000 route is very short, less than 5 years, and it requires no government funding or subsidies. Maglev-2000 routes can be financed by private investment.

Based on the 2nd generation Maglev-2000 system, a 25,000 mile National Maglev Network is envisaged (Figure 2) that would interconnect all major U.S. metropolitan areas. 70% of the U.S. population would live within 15 miles of a Maglev station, from which they could travel to any other Maglev station in the U.S.

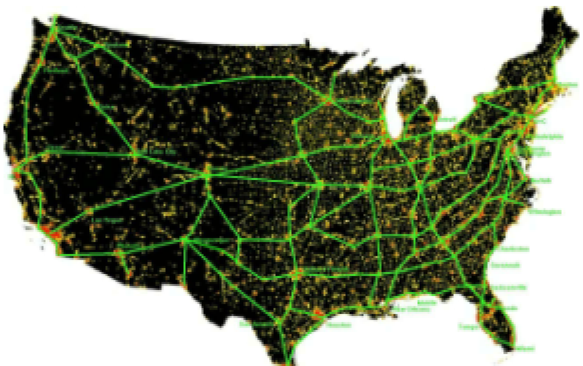


Figure 2 25,000 Mile National Maglev-2000 Network Map

Between cities, 300 mph Maglev-2000 vehicles would travel on elevated monorail guideways located on the rights-of-way of existing Interstate Highways . In urban/suburban regions, the levitated Maglev-2000 vehicles could travel along existing RR tracks. Thin, very low cost aluminum loop panels attached to the RR cross-ties would enable the Maglev-2000 vehicle to remain levitated and be magnetically propelled without contacting the steel rails on the tracks. Vehicle operating speed would be well below the 300 mph maximum, and dictated by local conditions. Once outside an urban/suburban area, vehicles would transition to high speed elevated guideways for travel to another metropolitan region. In urban/suburban regions where existing RR trackage was not available, an elevated guideway could be installed.

A unique capability of the Maglev-2000 system is its ability to electronically switch off the main guideway route to a secondary guideway that leads to an off-line station for unloading and loading. No mechanical switches are necessary. This capability allows a 2nd Generation Maglev vehicle to by-pass at high speed those stations that it is not scheduled to stop at. Stations can then be closely spaced, enabling convenient access, without slowing down the effective speed of the Maglev vehicle, since it would have express direct service to a limited number of stations on the route, rather than serve all stations. At a particular station, a passenger would only have to wait a few minutes until the vehicle scheduled to stop at his/her destination further along the maglev route came along.

In response to the recent rapid rise in the cost of oil, which has led to very high prices for gasoline, diesel, and jet airliner fuel, and considerable economic stress, the construction of High Speed Rail (HSR) passenger systems in high traffic corridors has been proposed. However, Maglev has major advantages over High Speed Rail, with much more favorable economics. Even in Europe and other densely populated areas that have HSR systems, their revenues are insufficient for HSR to be privately financed. Instead HSR requires government financing for construction and operation. In the less densely populated U.S., it is very likely that HSR will also require substantial government subsidization. Maglev systems, in contrast, can be privately financed by carrying long distance high revenue highway trucks, which is not possible for HSR.

Second, a few isolated HSR routes will only provide a minor benefit in meeting future U.S. transport needs. Each of the present U.S. transport systems, highways for autos and trucks, airplanes, and conventional railways, functions as a National Network, interconnecting all of America's population. Building a National Network of High Speed Rail lines would require massive government financing and subsidization. It is doubtful that HSR passenger traffic would be sufficient to economically justify a National HSR Network. The National Maglev Network, in contrast, can transport intercity highway tracks, which in the U.S. accounts for a much greater transport expenditure, than that for intercity passengers. The resultant economic and productivity benefits will be very large.

Maglev – The First New Mode of Transport Since the Airplane

Maglev is a completely new mode of transport, the first since the airplane in the early 1900's. Although Maglev vehicles travel along a guideway, Maglev is not just a higher speed train, but is fundamentally different.

Maglev vehicles do <u>not</u>:

- <u>Mechanically contact rails</u> – instead, they are magnetically levitated above, and travel along a guideway.
- <u>Have engines</u> – instead, they are magnetically propelled along the guideway by magnetic interaction of AC currents in the guideway with magnets on the levitated vehicle.
- <u>Travel as a long string of cars pulled by a heavy locomotive</u> – instead, they travel as individual units carrying passengers, or trucks, or personal autos or freight containers. At times when traffic loads are very heavy, consists of 2 or more vehicles can be coupled together to increase transport capacity.
- <u>Have long waits for service</u> – instead, by having Maglev vehicles travel as individual units, rather than long trains of many cars, the time interval between vehicles can be much less.
- <u>Use on-board operators to control vehicle speed and location along the guideway</u> – instead, Maglev vehicle speed and location is controlled by the frequency of the AC propulsion current in the guideway. To increase speed, the AC frequency is increased, to decrease speed, the AC frequency is decreased. The distance between different vehicles traveling along the guideways stays the same regardless of whether they experience different head or tail winds, or different up and down grades.

In contrast to High Speed Rail trains, Maglev vehicles <u>can</u>:

- <u>Carry highway trucks, personal autos, and freight containers</u> – in contrast, high speed rail can only carry passengers
- <u>Have increased energy efficiency</u> – in contrast, 300 mph Maglev uses less energy per passenger mile than 200 mph High Speed Rail.
- <u>Travel on high speed elevated guideways</u> – In contrast, High Speed Rail trains are too heavy to travel on elevated guideways, but must travel along on-grade RR tracks. High speed travel on elevated guideways is safer than on-grade travel. In addition, fenced on-

grade High Speed Rail lines drastically constrain surface accessibility – much more than an elevated monorail guideway.

- Travel at much higher speed – in contrast, High Speed Rail trains are limited by rail pounding and displacements to maximum speeds of ~200 mph. Maglev vehicles speed is only limited by air drag. Japan's Maglev system has operated at speeds up to 361 mph.

Maglev travel is very safe. Its safety features include:

- High speed operation on elevated guideways, isolated from any interaction with surface incidents.
- Inherent and automatic levitation of the moving vehicles (for superconducting Maglev systems), with very strong vertical and horizontal stability.
- Continued levitation of Maglev vehicles even if AC propulsion power to the guideway is cut off. The vehicles then coast to a designated location where it sets down on the guideway.
- Fixed distance between the sequential vehicles operating on the guideway, even if the vehicles are subjected to different external forces. The vehicles are phase locked into the AC current wave traveling along the guideway, and travel at its speed, much as a surfer rides a water wave. If, for example, a given maglev vehicle is traveling up-grade, while the Maglev vehicle behind it is traveling down-grade, the distance between them will not change even though the propulsion forces on the two vehicles will be different (the phase angle of the vehicle magnets relative to the AC current wave does change, however). The AC frequency is controlled by the traffic control center, who have constant real time information on the location of all vehicles on the guideway. As a result, there is no possibility of collisions between operating Maglev vehicles.

Why Maglev?

Maglev offers many important benefits. These include:

- Energy Benefits. Maglev is electrically powered, and does not consume oil. Used in combination with electric cars, Maglev can eliminate U.S. oil imports, which at $100 a barrel, account for over 500 Billion dollars per year for the U.S. trade deficit. Moreover, Maglev is very energy efficient. Per passenger mile, 300 mph Maglev uses only 1/10th as much energy as a 60 mph, 20 mpg automobile.
- Environmental Benefits. Maglev emits no greenhouse gases and pollutants. If powered by nuclear or renewable electric energy sources, it does not contribute any carbon dioxide to the global warming problem. Narrow monorail Maglev guideways can carry enormous volumes of passengers, trucks, freight, and personal autos, taking up much less land than multi-lane highways. Maglev also reduces environmental damage from oil drilling and shipping, and if coal is used to make synthetic fuels, damage from coal mining and release of toxic substances into the environment.
- Economic Benefits. Maglev will provide faster lower cost transport than existing modes. For example, a truck can pick up a load, roll-on to a Maglev vehicle and travel cross country at 300 mph instead of 60 mph by highway, at lower cost per ton mile. Shipping companies can deliver 5 times as much load per truck in their fleets than by going by highway, and at lower cost. This increases U.S. economic productivity and global competitiveness. In addition, the manufacture of Maglev guideways and vehicles can become a major U.S. industry with hundreds of thousands of new high paying jobs and

many Billions of dollars per year in exports. One container ship can carry 20 miles of pre-fabricated Maglev-2000 guideway and vehicles, ready to be quickly erected by conventional cranes at any site in the World.

- Quality of Life Benefits. Over 40,000 lives are lost each year on U.S. highways along with many hundreds of thousands of serious injuries. By transporting highway trucks by Maglev, and providing an affordable and attractive alternative to long distance auto trips, many thousands of deaths and serious injuries could be avoided. In addition, the reduction in toxic pollutants and micro-particulates emitted by autos and trucks would improve public health and lengthen lives. Studies of the effects of pollutants on public health have found that living in high traffic density areas can shorten peoples lives by as much as 2 years.

Besides public health benefits, Maglev offers a much faster, more comfortable, quiet way to travel with no delays due to weather or congestion in the airways and highways. Maglev will not generate the high noise levels produced by highway, rail, and air travel. Not only are these noise levels very objectionable to travelers, but they are also extremely annoying to people living in the vicinity of airports, highways, and railways.

The Second Reason for Why Maglev? is the fact that it is not realistic to expect that the U.S. and the World can continue to depend on the present oil fueled transport systems. What are the realities for future U.S. transport? They are pretty bleak for the oil fueled systems.

First,

- Conventional Oil Will Be Very Scarce and Expensive.

Figure 3 compares the World consumption rate of oil with the rate of discovery of new oil reserves. There is a large gap, and it is growing. For every 10 barrels consumed, only 4 new ones are discovered. Moreover, the new oil is in smaller and smaller oil fields and is increasingly more difficult and expensive to extract. World oil production has essentially plateaued and soon will start to decline at a rate of ~5% per year.

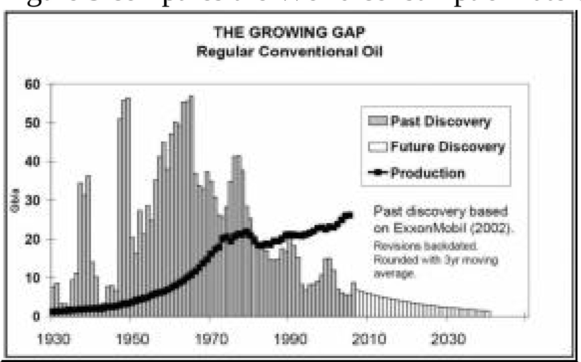


Figure 3 World Oil Discovery and Demand Rates vs Year

In addition, the U.S. consumes a much greater share per capita of World oil than the rest of the World does. This too will soon change. The U.S., with 5% of the World's population consumes 25% of the World's oil – 25 barrels per person per year compared to an average of 4 barrels per person per year for the rest of the World. As China, India, and other countries rapidly industrialize, their economies will grow and become stronger, enabling their per capita oil consumption to increase. There will be more competitors for an ever shrinking pie, and the U.S. share will drop drastically.

Second,

- The Supply of Biofuels is Small Compared to Needs.

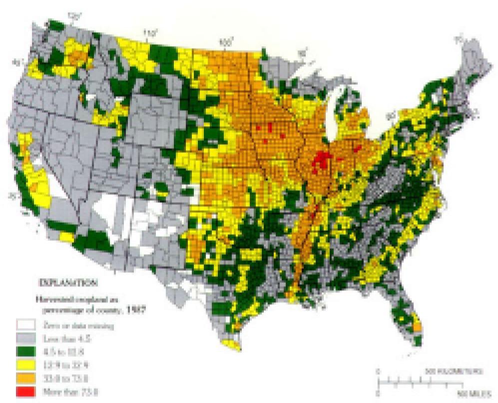


Figure 4 Map of U.S. Cropland

The recent enthusiasm for ethanol has greatly faded. 20% of the U.S. corn crop goes towards making 6.5 Billion gallons of ethanol per year (Figure 4). A gallon of ethanol does not equal a gallon of gasoline, however. On a combustion basis one gallon of ethanol equals 2/3 of a gallon of gasoline (80,000 BTU per gallon compared to 120,000 BTU per gallon). The comparison becomes even less favorable when the energy required to make the fertilizer to grow the corn, and the energy needed to harvest, transport, and process the corn into ethanol is deducted. On a net energy basis, according to USDA analyses, 1 gallon of ethanol only equals ¼ of a gallon of gasoline (30,000 BTU per gallon compared to 120,000 BTU per gallon). Thus the 6.5 Billion gallons of ethanol per year only displaces 1.6 Billion gallons of gasoline, less than 1% of the 180 Billion gallons of gasoline and diesel fuel that America consumes annually.

Moreover, growing crops to make biofuels dramatically drives up food prices, as evidenced by recent experience, and increases hunger and malnutrition around the World. Some claim that growing switchgrass and other non-food crops to make biofuels does not deprive people of food, but the argument is specious. Arable land is limited in the World, and using it for biofuels, when it could be used to grow food for the hundreds of millions of people who go hungry, is wrong.

Third,

- The Dream of Hydrogen Fuel for Transport is a Fantasy.

Free hydrogen does not exist in Nature, but must be manufactured, either from fossil fuel, or by electrolyzing water. Manufacturing hydrogen from fossil fuel will release more carbon dioxide into the atmosphere than using it directly or converting it to synfuels. Electrolyzing water requires enormous amounts of energy. To make hydrogen with the energy equivalent of 1 gallon of gasoline requires 50 KWH(e) of electricity, assuming an electrolyzer efficiency of 80%, which is optimistic. To make the equivalent of 180 Billion gallons of gasoline plus diesel fuel, the U.S. annual consumption, would require 9 Trillion KWH(e), just for Hydrogen production, more than twice as great as the current total U.S. electrical generation of 4 Trillion KWH (e) per year. Used in fuel cell powered vehicles, hydrogen would yield a greater energy efficiency than oil fuel, so that the electrical energy required for hydrogen production would be less than 9 Trillion KWH(e). However, the U.S. would still need to generate an additional 5 to 6 Trillion KWH(e) more than its present electrical production to support a hydrogen transport economy.

In addition there are serious safety and security problems with a massive shift to hydrogen fueled autos and trucks. Several auto companies are testing and driving hydrogen fueled autos.

The hydrogen fuel is either stored as compressed gas in a tank at very high pressure (5000 or 10,000 psi) or as liquid hydrogen at very low temperatures (-420F) in an insulated cryogenic tank. If the hydrogen were to escape from the tank and mix with the ambient atmosphere, it could be detonated by an extremely tiny flame or spark – orders of magnitude less than an ordinary matchstick. The explosive energy of a hydrogen tank with the energy equivalent of 10 gallons of gasoline would be quite large – about 500 pounds of TNT.

The thought of 200 million hydrogen fueled cars driving bumper to bumper at 70 mph on America's crowed highways is scary enough, but the prospect of hydrogen fueled cars in the hands of terrorists, criminals, and psychopaths is even scarier. A million cars are stolen in the U.S. every year. It would be very easy for someone to place a small package on the hydrogen tank, that when triggered by a timer or a cell phone call, would drive a projectile through the tank wall (essentially a nail gun) allowing the hydrogen to escape into the surrounding air, followed by a very small spark that detonated the hydrogen – air mixture. Parked on a busy city street, or in a garage with other hydrogen fueled cars, such incidents could cause tremendous loss of life and damage. The perpetrators would be free to continue their campaign of terror, with serious damage to the ability of society to function. It is very doubtful, that because of such problems, hydrogen transport will play an important role in the future.

Fourth,

- <u>Oil From Coal and Shale Will Speed Global Warming</u>

While conventional oil reserves are dwindling and World production will soon start to decline there is an enormous amount of oil potentially available by conversion of coal to synfuels and by mining oil shale. The processes are known and technically practical. However, in addition to the great environmental damage that mining the coal and shale would do, the effects on global warming would be disastrous. The average American auto emits 10 tons of carbon dioxide emissions. This would increase to 20 tons per year, when the carbon dioxide produced by the conversion process is included. World transport carbon dioxide emissions account for ~30% of the total 25 billion tons of carbon dioxide per year. The rapid increase in the World's car population, plus the doubling of carbon dioxide generation that accompanies the conversion of coal to synfuels, could increase World carbon dioxide emissions from transport alone to well over 25 billion tons per year. Atmospheric carbon dioxide concentrations are increasing at the rate of 2 parts per million per year (Figure 5), 10,000 times more rapidly

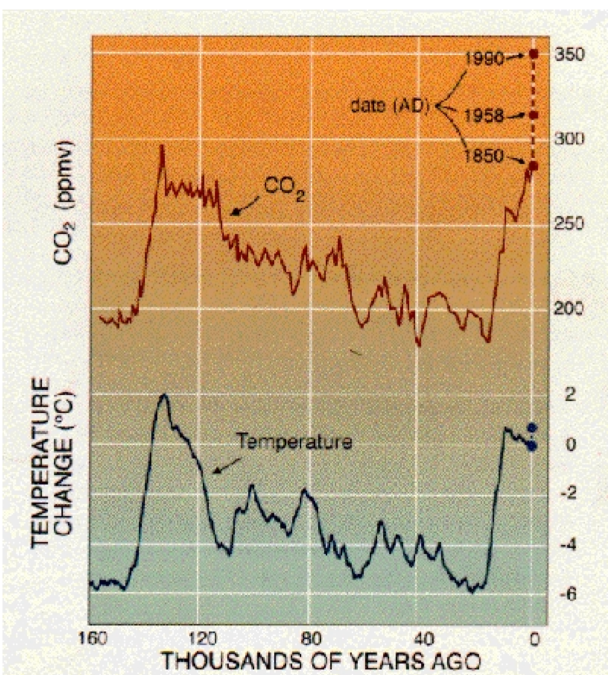


Figure 5 CO_2 Atmosphere Concentration vs Year

than any previous time in Earth's history. Carbon dioxide atmospheric concentrations are now at 380 ppm, more than 100 ppm greater than at the start of the Industrial Revolution. Synfuel production from coal and oil shale could cause the carbon dioxide concentration to increase at 4 ppm per year. In just 25 years, atmospheric carbon dioxide levels would approach 500 ppm, with disastrous effects on Earth's climate – more droughts, severe storms, spread of tropical diseases, etc. At some point, Earth will reach an irreversible tipping point, such as the extinction of most marine life due to ocean acidification, or a runaway greenhouse effect due to the release of stored greenhouse gases in the ocean beds and permafrost regions. It is clear that synfuels cannot be relied on to meet long-term transport needs – the environmental damage and risks are far too great.

Status of Maglev

There are 2 basic types of Maglev. In Superconducting Maglev, invented by Powell and Danby in 1966 (Figure 6) superconducting magnets on the moving maglev vehicles induce currents in a sequence of independent aluminum loops located along the guideway. These induced currents magnetically interact with the superconducting magnets on the vehicle, causing it to levitate. The levitation is inherent and strongly stable. As the gap between the vehicles and the aluminum loops become smaller, the induced current and levitation force become greater, forcing the vehicle away from the guideway. As the gap becomes greater, the

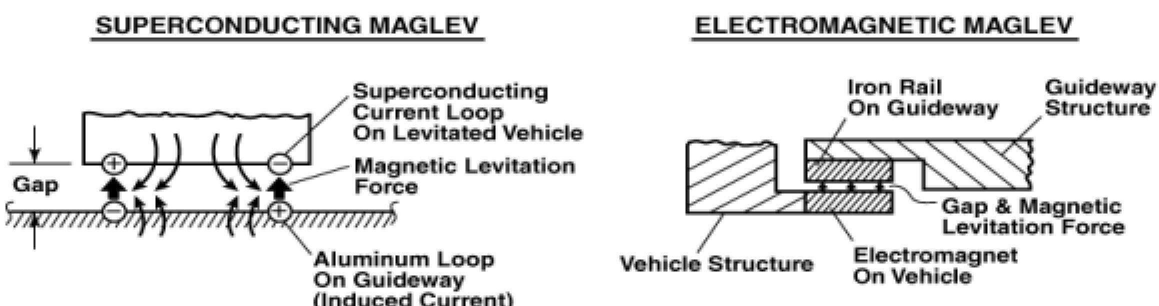


Figure 6 Superconducting and Electromagnetic Maglev

induced current and levitation force becomes smaller, causing gravity to push the vehicle towards the guideway. The vehicle thus finds an equilibrium position above the guideway, and automatically magnetically resists any external force (winds, curves, up and down grades, etc.) that try to displace it from equilibrium. The vehicles magnet/guideway loop configuration is designed so that the vehicle is inherently stable in both the vertical and horizontal directions, but free to move unhindered along the guideway. No external force, even hurricane winds, can make the vehicle contact the guideway.

The very strong magnetic strength of superconducting magnets enables a large gap between the vehicle and the guideway, in the range of 4 to 6 inches. Superconducting Maglev is the basis for the 1st generation Japanese Maglev system.

The 2nd type of Maglev is Electromagnetic Maglev (Figure 6). Instead of superconducting magnets that induce a repulsive magnetic force between the vehicle magnets and aluminum guideway loops, electromagnetic Maglev uses conventional electromagnets on the vehicles that produce an attractive upward force towards iron rails mounted on the guideway. This approach forms the basis for the 1st generation German Transrapid Maglev System.

The attractive magnetic force is inherently unstable (Think permanent magnets attracted to a refrigerator door). As the vehicle magnet gets closer to the iron rail, the attractive force gets stronger. To prevent contact the magnetic force is controlled on a very fast time scale, thousandths of a second. If the gap between the vehicle magnet and the iron rails on the guideway decreases, the current to the electromagnets is decreased, reducing the attractive magnetic force. If the gap increases, the magnet current is increased, causing the attractive magnetic force to increase. The servo control system thus maintains the gap at its desired value.

Because electromagnets are much less powerful than superconducting magnets, the gap between the vehicle and the guideway is much smaller for Electromagnetic Maglev than for Superconducting Maglev, e.g. ~ 3/8 inch, compared to 4 to 6 inches. This very small gap necessitates very precise construction of the guideway, with much more exacting tolerances for Electromagnetic Maglev, as compared to Superconducting Maglev. This requirement for very precise construction greatly increases construction cost.

Figure 7 shows a photo of the 1st generation Superconducting Maglev System now operating in Japan. Based on Danby and Powell's 1966 invention of superconducting Maglev, Maglev vehicles operating on the 21 Kilometer demonstration guideway in Yamanashi Prefecture have carried well over 50,000 passengers at speeds up to 360 mph. Japan plans to build a 300 mile Maglev route between Tokyo and Osaka. The route, to be completed by 2025, will carry 100,000 passengers daily each way.

Figure 7 View of Operating Japanese Maglev Vehicle

Figure 8 shoes a photo of the German Electromagnetic Maglev System, termed Transrapid. First, demonstrated on the guideway in Emsland, Germany, Transrapid vehicles are now operating on a 21 mile commercial Maglev route in Shanghai, China, connecting its Pudong airport with the city center.

Figure 8 View of Operating Transrapid Maglev Vehicle

Both Systems have limitations that have hindered large scale implementation. First, both are passenger only systems, and cannot carry highway trucks, freight and personal autos. Both have very high guideway construction costs, over 60 million dollars per 2 way mile, and require major government funding and subsidies to operate, since revenues are too small to attract private investment.

In particular, proposed Transrapid projects have been cancelled because of the very high construction cost, e.g. ~5 Billion dollars for a 24 mile line between Munich and its airport. Moreover, Thyssen-Krupp and Siemens, the industrial arm of Transrapid, have withdrawn their support for the company.

The 2nd generation Maglev-2000 System (Figure 1) currently being developed by Powell and Danby has been designed to overcome these limitations. Just as autos and airplanes evolved from early 1st generation designs to much more capable levels, so will Maglev. If airplanes had stayed at the level of the Ford Tri-Motor and DC-3's, for example, and not evolved into today's modern jet liners, air travel would still be a rare oddity.

The Maglev-2000 system achieves a number of important advances:
First, its guideway is much cheaper to build and much easier to erect. The monorail guideway (Figure 1) can be mass produced in large factories at low cost and shipped by truck or rail to the construction, there to be quickly erected by conventional cranes. The monorail guideway beams would have their loop panels and other equipment already attached, and could be ready for operation immediately after erection.

Full scale Maglev-2000 guideway components have been successfully fabricated and tested. Based on the fabrication experience, the projected cost for the monorail guideway is 20 million dollars per 2 way mile, compared to over 60 million dollars per 2 way mile for the 1st generation Maglev system.

Key to Maglev-2000's unique capabilities is its superconducting quadrupole magnets (Figure 9). 1st generation Maglev systems travel on a fixed guideway configuration. In contrast, Maglev-2000 vehicles can travel on either monorail guideways or planar guideways (Figure 10). On monorail guideways, the sides of the quadrupoles magnetically interact with aluminum loop panels mounted on the opposite sides of the guideway beam, as shown in Figure 10. On planar guideways, the bottoms of the quadrupoles magnetically interact with aluminum loop panels mounted on the surface of the planar guideway.

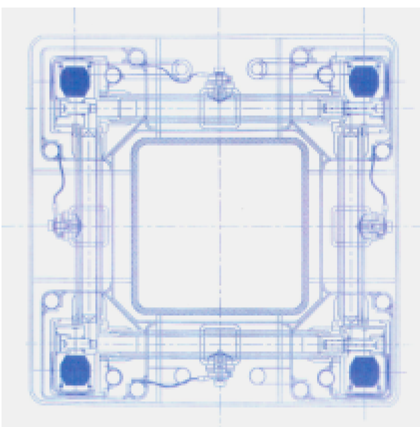


Figure 9 Cross Section of Maglev-2000 Superconducting Quadrupole Magnet

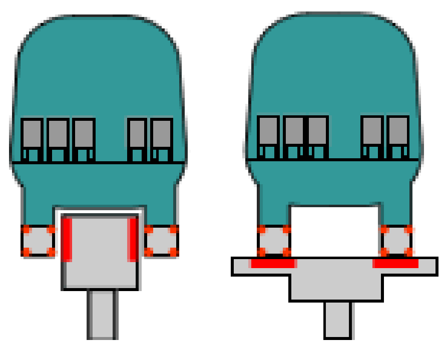


Figure 10 Monorail & Planar Guideways -For Maglev-2000 Vehicles

Using the planar guideway configurations, Maglev vehicles can electronically switch at high speed from the main guideway line onto a secondary guideway that leads to an off-line station for unloading and loading. This capability enables the Maglev-2000 system to have many more stations than 1st generation Maglev or High Speed Rail systems that require low speed mechanical switches, or that require vehicles to stop at every station on the main-line. Maglev-2000 vehicles can by-pass stations at high speed that they are not scheduled to stop at, to stop only at stations where they are scheduled to stop.

The unique ability to travel on planar guideways can also enable Maglev-2000 vehicles to travel along existing RR tracks in a levitated mode (Figure 11). By attaching thin, very low-cost aluminum loop panels to the cross-ties of the RR tracks, the magnetic interaction between the bottoms of the superconducting quadrupoles will magnetically levitate and propel the vehicle along the RR trackage and back again. With this capability, Maglev-2000 vehicles could travel at high speed between cities on monorail guideways and then transition to existing RR trackage in urban/suburban regions.

Figure 11 Levitate Maglev-2000 Vehicle on Existing RR Tracks

Besides the benefits of the Maglev-2000 superconducting quadrupole with regard to its ability to travel on monorail guideways as well as existing RR tracks, the quadrupole configuration also results in much lower magnetic fringe fields, so that passengers in Maglev-2000 vehicles do not experience a magnetic field strength that is greater than Earth's ambient field. The quadrupoles can thus be placed all along the length of a Maglev 2000 vehicles, which is not the case for the 1st generation Japanese Maglev system. The capability for additional magnets allows Maglev-2000 vehicles to carry much heavier loads, such as fully loaded highway trucks. (Figure 12).

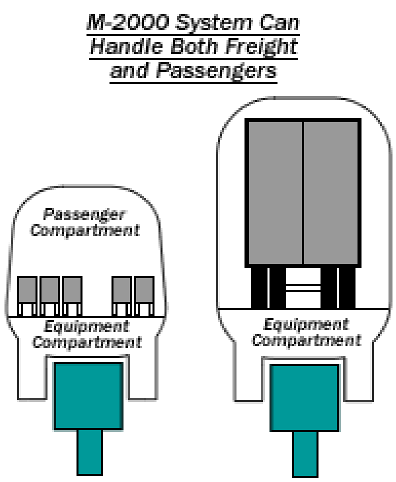


Figure 12 Maglev-2000 Vehicles for Transport of Highway Trucks and Passengers on the Elevated Monorail Guideway

<u>Energy Efficiency of Maglev</u>

Figure 13 compares the energy efficiencies of the various modes of passenger transport, in terms of the number of barrels of oil or oil equivalent (BOE) per 10,000 passenger miles. Autos, SUVs, transit buses, airplanes, and intercity rail are all on the order of 7 to 8 BOE per 10,000 passenger miles. Commuter rail and transit rail are slightly less, about 6 BOE per 10,000 miles.

Intercity Bus and Maglev are much less than the other transport modes, with Intercity Bus al~2 BOE and 300 mph Maglev at ~0.5 BOE per 10,000 passenger miles. The much lower energy consumption for maglev is due to the fact that Maglev does not have mechanical friction energy losses – only air drag energy losses plus a small amount of I^2R losses in the aluminum guideway loops, due to their non-zero electrical resistance. When a Maglev vehicle passes over an aluminum loop, the induced current in the loop results in a momentary I^2R loss.

Air drag power scales as V^3 where V is the speed of the Maglev vehicle, while energy loss in KWH(e) per passenger mile scales as V^2. The I^2R loss power is independent of vehicles speed, so that its energy loss per passenger mile scales as 1/V. Table 1 shows the dependence of the total energy loss per passenger mile on vehicles speed. At 300 mph, energy loss is 0.54 Megajoule per passenger mile, dropping to 0.20 megajoules per mile at 150 mph. In comparison, the energy consumption for a 60 mph, 20 mph automobile is 7.0 megajoules per passenger mile. At 4 dollars per gallon the energy cost per passenger mile for Maglev is a factor of 100 or more smaller than for auto travel.

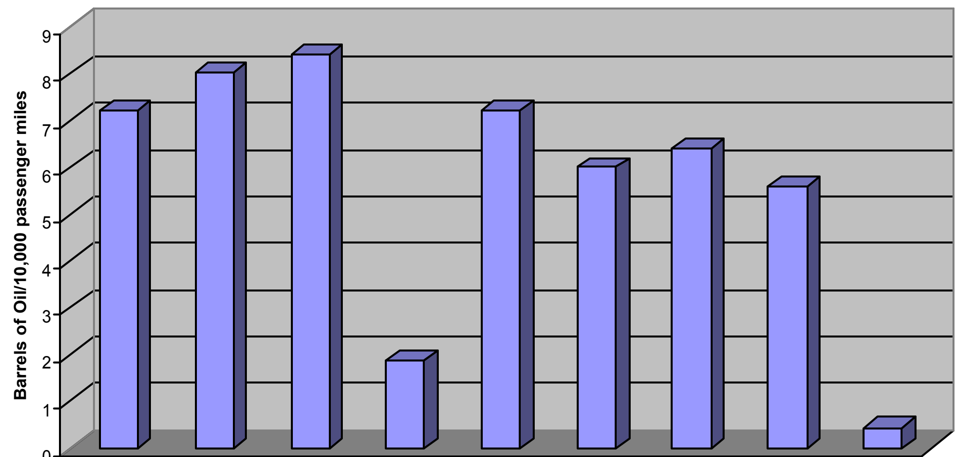
A similar pattern is found for urban/suburban vehicles that are designed for service in the local metropolitan area, and not intended for high speed intercity travel. These vehicles would operate on the same urban/suburban guideways and modified RR trackage that would be used by the intercity Maglev vehicles. However, they would carry only 60 passengers compared to the 100 passengers carried by intercity Maglev vehicles. At 150 mph, Maglev urban/suburban vehicles would have an energy usage of 0.29 megajoules per passenger mile, compared to 7.0 megajoules per passenger mile for automobiles. The energy usage is essentially constant over the speed range of 75 to 150 mph.

Maglev-2000 vehicles can also be used as people movers. In this application, the maximum vehicle speed will probably be in the range of 30 to 40 mph, with frequent stops for passengers to board and leave. For a nominal travel distance of 500 meters (1500 feet) and an average speed of 30 mph between stations, the trip time would be 40 seconds (Table 3). With a nominal capacity of 30 passengers the time at a station would be on the order of 1 minute, resulting in an average speed of ~12 mph, including station stops – about 4 times faster than normal walking speed.

Air drag energy losses would be negligible. To be self-levitated, Maglev-2000 people mover vehicles will require a speed on the order of ~15 mph. Below that speed, the non-zero electrical resistance of the aluminum loops in the guideway causes the currents induced by vehicle motion to decay enough that the vehicles will not self-levitate (Above ~15 mph, the L/R decay of the induced currents is small enough that the vehicle will self-levitate.)

However, levitation can be maintained below 15 mph by energizing the aluminum loops in the guideway with electrical current from an external power source – in fact levitation can be maintained even when the vehicle is standing still at the station. Alternatively at stations, the stopped vehicles could be supported by hydraulic supports attached to the platform, which would eliminate the need for an applied current when stationary. When it was time for the vehicle to leave the station, the aluminum guideway loops would be energized with current to levitate the vehicle and magnetically accelerate it away from the station.

Because of the low speed of the people mover vehicle, and its smaller passenger capacity, the energy requirements per passenger mile are significantly greater than those for the high speed intercity and urban/suburban Maglev vehicles. With levitation at the station, for example, the energy requirement for the people mover vehicle is 0.30 KWH(e) per passenger mile (Table 3), compared to 0.149 KWH(e) per passenger mile for a 300 mph intercity Maglev vehicle (Table 1) and 0.082 KWH(e) for a 150 mph urban/suburban vehicle (Table 2). By using hydraulic supports at the station, however, an energy consumption of 0.12 KWH(e) per passenger mile can be achieved, putting the people mover energy demand at a level comparable with that for the high speed Intercity and the moderate speed urban/suburban vehicles. In any case, the Maglev people mover will have a much smaller energy requirement per passenger mile than a transit bus (Figure 13).



	60 mph Autos	60 mph SUVs&Lt Trucks	30 mph Transit Bus	60mph Intercity Bus	500 mph Air	80 mph Intercity Rail	60 mph Commuter Rail	40 mph Transit Rail	300 mph Maglev
Series1	7.2	8	8.4	1.86	7.2	6	6.4	5.6	0.46

Figure 13 Energy Efficiency by Transport Mode In Barrels of Oil or Oil Equivalent Per 10,000 Passenger Miles

The National Maglev-2000 Network

Figure 14 shows a map of the 25,000 mile National Maglev-2000 Network, together with a

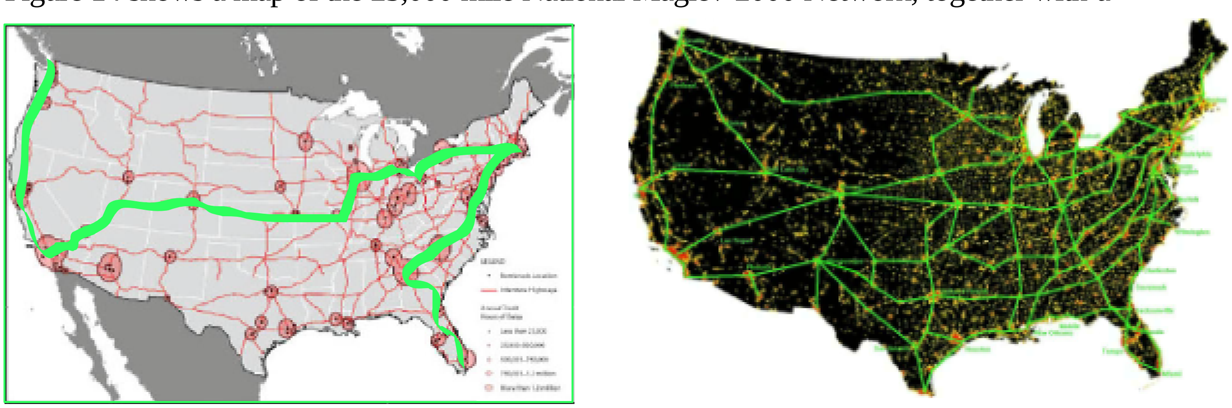
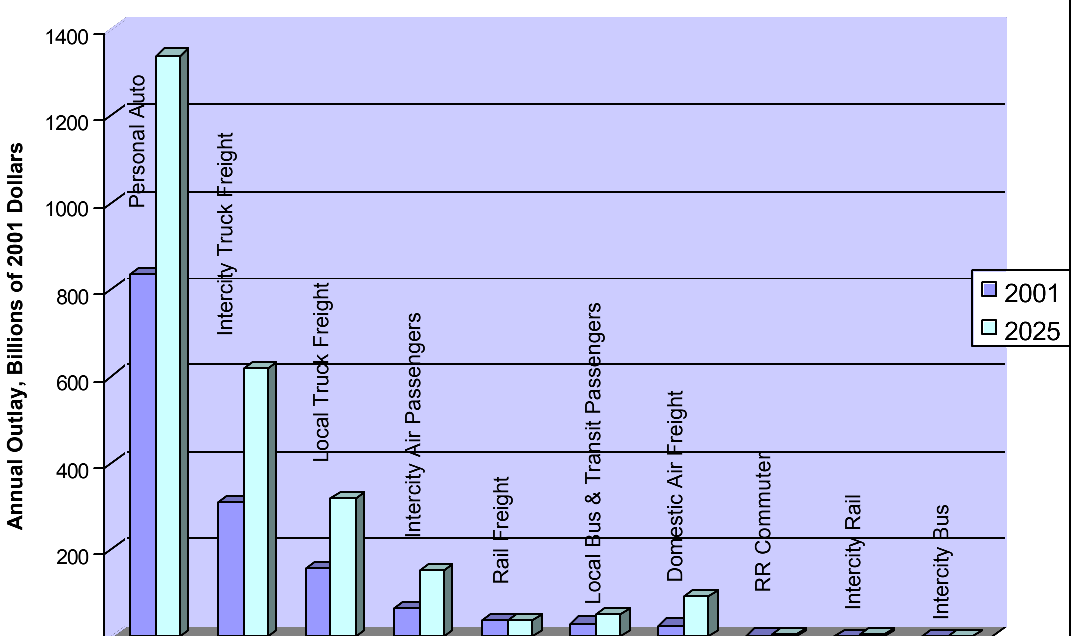


Figure 14 Maps of the National Maglev Network: Initial Golden Spike Phase and Final 25,000 Mile Network

map of its first phase, the Golden Spike Project. The National Network would interconnect all major metropolitan areas in the U.S. with high speed Maglev routes, using the rights of way along the existing Interstate Highway System. The 300 mph Maglev-2000 vehicles would operate on elevated monorail guideways, which would be prefabricated in large factories. The guideway beams and piers would be trucked to the construction site and quickly erected by conventional cranes onto pre-poured concrete footing for the piers. After erection, the AC propulsion windings in the beams would be electrically connected together, and the Maglev-2000 System would be ready for operation.

In urban and suburban areas, the Maglev-2000 vehicles would transition to existing RR trackage that had been adapted with low cost aluminum panels on the cross-ties, to allow levitated travel. (The RR trackage could still be used by conventional trains with appropriate scheduling). This capability enables Maglev-2000 vehicles to serve multiple stations in the metropolitan area, without having to build an extensive network of guideways in the area at high cost, and disrupt the existing infrastructure. In metropolitan regions where existing RR trackage is not available – a relatively small fraction of the total – dedicated guideways could be built.

With the National Network, 70% of the U.S. population would live within 15 miles of a Maglev Station, from which they could reach any other station in the U.S., crossing the country in a few hours. It is critically important to have an interconnected Network, rather than isolated routes that do not interconnect. Imagine having airplane travel that only connected two cities together, without them being connected to other cities in the country by air. The existing U.S. transport systems – highway, air, and conventional rail – all function as interconnected networks.



	1	2	3	4	5	6	7	8	9	10
2001	836	309	158	65	37	31	26	4	3	2
2025	1340	620	320	152	37	50	93	7	5	3

Mode of Transport

Figure 15 Annual Outlays, Current and Future, for US Transport Modes

Individual High Speed Rail (HSR) routes have been proposed for various locations in the U.S. However, individual Systems that did not interconnect into a National Network would be of limited utility, since there are only a few routes where traffic would be high enough to justify HSR, even with government subsidy.

Figure 15 shows the present and projected outlays for the different U.S. transport modes. After personal autos, the dominant transport outlay is for intercity highway trucks. Outlays were ~300 Billion dollars per year in 2001, and projected to increase to 600 Billion dollars annually by 2025 AD. The average intercity truck haul distance is ~500 miles. Using long distance transport of Roll-on, Roll-off trucks on Maglev-2000, a trucker could pick up a load, drive a few miles to the nearest Maglev station, and then travel at 300 mph to the station nearest to his destination, there to drive off and deliver the load. Shippers would be very attracted to Maglev transport, because the cost would be less than driving by highway, and a truck could deliver 5 times as much load per unit time, due to its much shorter trip time.

Intercity passenger travel outlays are much smaller than intercity truck outlays. Per year, in 2001, air passenger outlays were about 60 Billion dollars, intercity passenger rail, about 3 Billion dollars, and intercity bus, about 2 Billion dollars. Intercity passenger transport, while very important, will not generate sufficient revenues to attract private investment to build the National Maglev Network, but intercity truck transport can.

Figure 16 compares the payback time for a Maglev-2000 route that only carries passengers (curve B) with a Maglev route that only carries highway trucks (curve A) as a function of the traffic carried by the route. The projected cost of the route is 25 million dollars per 2 way mile. The gross revenue for passengers is taken as 10 cents per mile, which is considerably less than the cost of driving. At 4$ per gallon, a 20 mpg car costs 20 cents a mile just for gas, plus the additional substantial costs for auto depreciation, insurance, maintenance, tires, tolls, etc. Maglev operating costs for vehicle amortization, energy and personnel (Table 4) total 2.6 cents per passenger mile, providing a net revenue of 7.4 cents per passenger mile.

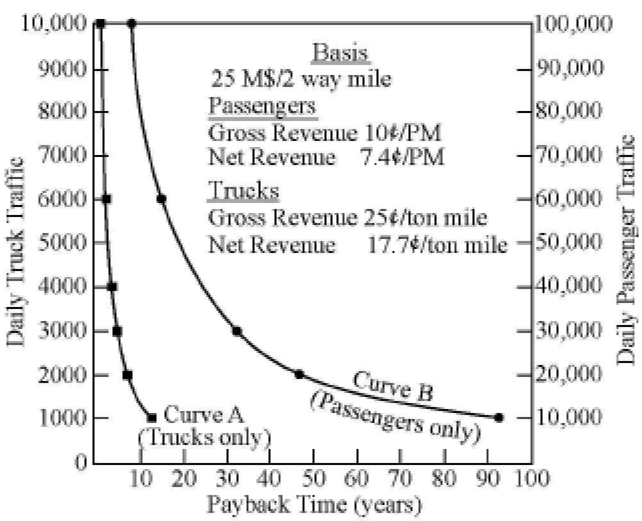


Figure 16 Payback Time for Maglev-2000 Guideway

The gross revenue for intercity trucks is taken as 25 cents per ton-mile. This is less than the present average outlay of 30 cents per ton mile for highway trucks, which includes fuel, truck amortization and maintenance personnel, tolls, etc. Maglev operating costs for intercity truck transport – vehicle amortization, energy, and personnel – are estimated to be 7.3 cents per ton mile (Table 4), resulting in a net revenue of 17.7 cents per ton mile.

Even in Europe, which has a very well developed High Speed Rail (HSR) systems, the typical passenger traffic on a route is approximately 10,000 passengers daily. On the Eurostar route through the Chunnel that links France to England, which is the most heavily traveled route, traffic is only about 20,000 passengers daily.

At 10,000 passengers per day, it would take almost 100 years to payback the construction cost of a Maglev-2000 route if it only carried passengers (and many hundreds of years for the much more expensive 1st generation Japanese and German Maglev Systems.) High Speed Rail lines will also take many years to payback, since they can only carry passengers, and not high revenue highway trucks and cargo. At 10,000 passengers per day and 25 million dollars per 2-way mile, curve B in Figure 16 shows the payback time to be 100 years for a HSR route.

Table 4: Vehicle O&M Costs

5 M $ vehicle cost; 10 year Amortization; 5%/year maintenance; 100 passenger or 30 ton capacity; 80% load factor; 12 hours op/day; 250 mph average speed; 3 MW propulsion power for passenger vehicles, 4 MW for trucks; 6 cents/KWH

Revenues & Costs	Passengers (cents/pm)	Trucks (cents/ton mile)
Gross Rev	10	2.5
Energy Cost	1.2	4.0
Am& M Cost	0.9	2.8
Personnel Cost	0.5	0.5
Net Rev.	7.4	17.7

In contrast, by carrying 3000 trucks per day, the construction cost of the Maglev-2000 route could be paid back in less than 5 years (Figure 15). 3000 Trucks daily is only 1/5th of the average truck traffic on a typical Interstate Highway(some routes carry 25,000 trucks daily).

Clearly, to attract private investment, the National Maglev-2000 Network has to transport trucks as well as passengers. Without truck carrying capability, the Network would require government funding and subsidies. With truck transport the 500 Billion dollar Network could be privately financed following government certification of the Maglev-2000 system.

The 25,000 National Maglev Network would be completed by 2030 AD. The first phase , the Golden Spike Project (Figure 14) would be operating by May 2019, the 150th Anniversary of the completion of the Transcontinental Railroad in 1869, commemorated by the driving of the Golden Spike. The project would have 6000 miles of Maglev routes –E-W route connecting the East and West Coasts, and 2 North-South routes along the East and West Coasts. While challenging, the rate of construction of Maglev routes would be less than the rate of construction of the Interstate Highway system initiated by President Eisenhower.

The National Maglev-2000 Network, operating in conjunction with the transition to electric automobiles, would eliminate oil imports to the U.S., reducing the trade deficit by over 500 Billion dollars annually. Also, the U.S. would no longer be vulnerable to sudden cut-offs in supply of oil from abroad and rapid spikes in the price of oil.

Implementing Maglev in the U.S. and the World

The 1966 invention of superconducting Maglev by Powell and Danby sparked World-wide interest in Maglev and started major development programs in Japan and Germany that have led to their present 1st generation operating systems.

In the U.S., 3 small Maglev programs were initiated with limited funding, but were cancelled a few years later when the Department of Transportation decided that autos and airplanes would be the preferred modes of transport into the indefinite future. Germany and Japan continued their Maglev development programs.

U.S. activity in Maglev revived in 1989, when Senator Daniel Patrick Moynihan, chairman of the Senate Environment and Public Works Committee became interested in Maglev. Senator Moynihan proposed a Network of Maglev routes that would be built on the rights-of-way alongside the U.S. Interstate Highway System. His Maglev Task Force, which we co-chaired, provided input to the Senate Committee.

In 1990, Senator Moynihan sponsored legislation for a 750 million dollar Maglev development program. It passed the Senate, but was killed in the House of Representatives by vested transport interests. Had it become law, the U.S. would now have an operating Maglev Network.

As Germany and Japan moved to finalizing the development of their 1st generation Maglev Systems in the late 1990's. 7 U.S. sites were selected for study of possible Maglev routes. 6 of the 7 sites proposed building the German 1st generation Transrapid system. The seventh site in Central Florida proposed developing the 2nd generation Maglev-2000 system.

Full-scale Maglev-2000 hardware components (quadrupole magnets, aluminum loop guideway panel, a full length monorail guideway beam, and a 60 passenger vehicles fuselage and undercarriage) were fabricated and successfully tested as part of the Florida Deployment Study.

The routes were then down-selected to 2 routes, Baltimore-Washington and Pittsburgh. However, funding has only been sufficient to continue study of possible routes. There has been no funding to actually build them. In fact, the Maryland legislature has passed legislation prohibiting funding of the Baltimore-Washington route because of its very high cost.

Subsequently, Maglev-2000 has proposed government funding of a U.S. Maglev test facility similar to those that have been funded by the governments of Japan and Germany. The facility would test and advanced 2nd generation U.S. Maglev System, such as Maglev-2000, on an operating guideway , with the goal of demonstrating and certifying it. So far, however, while there has been substantial interest in such a facility, no action has been taken.

As discussed previously, the present Japanese and German 1st generation passenger only Maglev Systems are too expensive and too limited in capability to form the basis for the National Maglev Network. An advanced 2nd generation system that is much less expensive, and that can transport high revenue trucks and freight containers, enabling a short payback time that will attract private investment, is required if Maglev is to be an important mode of transport in the U.S.

The proposed U.S. Maglev test facility would carry out a 3 phase, 5 year program to demonstrate and certify the advanced 2nd generation Maglev system. It would test Maglev vehicles on elevated guideways at speeds up to 300 mph, as well as Maglev vehicles on RR tracks that had been fitted with aluminum loop panels that enabled levitated travel. Different kinds of Maglev vehicles would be tested and certified, including vehicles for transport of passengers, vehicles for transport of roll-on, roll-off highway trucks and freight containers, and vehicles for transport of personal autos.

Phase 1 would test vehicles on a 1 mile section of guideway at speeds up to 100 mph, including vehicles capable of urban/suburban service. Phase 2 would test vehicles on a 4 mile section of guideway at speeds up to 300 mph, capable of high speed intercity service. Phase 3 would test vehicles on a 20 mile section of guideway for long-term running service, so that they could be certified for public use.

The projected total cost for the 5 year testing program is 600 million dollars, or 120 million dollars per year. This is 1/5000th of the annual cost that the U.S. pays for its oil imports. Successful completion of the 5 year program would allow the U.S. to eliminate most, if not all, of the annual cost of importing oil – a tremendously important benefit. As described earlier, the 1st phase of implementation, the 6000 mile Golden Spike project to interconnect the East and West Coasts, along with N-S routes along both coasts, would be fully operating by May 2019, the 150th Anniversary of the Transcontinental Railroad. The complete 25,000 mile National Maglev Network would be in full operation by 2030.

Summary and Conclusions

Maglev will be a major mode of World Transport in the 21st Century because of its many important benefits in terms of:

- Much higher energy efficiency
- Independence from oil
- Elimination of greenhouse gas emissions
- Much lower transport cost than other modes, including highways, airways, and high-speed rail
- Does not need government financing and subsidies
- Reduced accidental deaths and injuries and damage to public health from pollutants
- Faster, more convenient transport
- Improved economic productivity

In the U.S., the 25,000 mile National Maglev-2000 Network, in combination with electric automobiles, could completely eliminate oil imports by 2030 AD. It would interconnect all major U.S. metropolitan areas by 300 mph Maglev vehicles operating on elevated monorail guideway erected on the rights-of-way alongside the existing Interstate Highway System. In urban/suburban regions, the Maglev-2000 vehicles would operate on existing RR trackage on which thin, ultra-low cost aluminum loop panels had been attached to the cross-ties, enabling levitated travel of the Maglev-2000 vehicles. The unique electronic switching capability of the Maglev-2000 system enables vehicles to electronically switch off the main guideway route to off-line stations for unloading and loading operations. Maglev-2000 vehicles can then travel at full speed along the main guideway, switching off to the stations they are scheduled to stop at, and by-passing these that are not scheduled for stops. In this manner, high average vehicle speed can be maintained, even where there are multiple closely spaced stations for convenient access.

Maglev-2000 vehicles can be configured to carry different types of transport – passenger only, highway trucks, freight containers, and personal autos. The revenues from transporting on Maglev just 1/5th of the highway trucks now on traveling Interstate Highways will pay back the cost of a Maglev route in less than 5 years. As a result, the Maglev-2000 National Network can be privately financed once it has been demonstrated at the Maglev Test Facility.

By developing a U.S. based 2nd generation Maglev System, America has the opportunity to become the World leader in 21st Century Transport. An American Maglev industry would generate hundreds of thousands of new jobs, and many Billions of dollars in annual exports. One container ship can carry 20 miles of pre-fabricated Maglev-2000 guideway along with Maglev vehicles.

However, the container ships can either sail out of U.S. Seaports, or into them, bringing Maglev guideways and vehicles from abroad. The U.S. still has the opportunity to develop the 2nd generation system. If it does not act now to seize this opportunity, the advanced Maglev system will be developed abroad and exported to the U.S., adding to our trade deficit and declining manufacturing industry.

Table 1

Propulsion Power and Energy Requirements for High Speed
Intercity Maglev Vehicles as a Function of Speed

Basis:
100 Passenger Maglev Vehicle
11 m^2 Frontal Area
0.22 Effective Drag Coefficient
90% Efficient LSM Propulsion
10 cents/kWh(e)
$4/Gallon Gasoline, 60 mph, 20 mpg Automobile
1 kWh = 3.6 Mega Joules (MJ)

Speed (mph)	Air Drag Power KW(e)	I^2R Drag Power KW(e)	Total Drag Power KW (e)	Total Drag Power/LSM Eff KW (e)	Energy Per Passenger Mile kWh(e)/PM	Energy Cost/PM $/PM	Energy/PM MJ/PM	Energy for Auto MJ/PM	Auto Gas Cost/M $/P
300	3720	300	4020	4460	0.149	$0.015	0.54	7.0	0.2
250	2150	300	2450	2720	0.109	$0.011	0.39	ditto	ditto
200	1100	300	1400	1550	0.078	$0.008	0.28	ditto	ditto
150	465	300	765	850	0.057	$0.006	0.20	ditto	ditto

Table 2

Propulsion Power and Energy Requirements for Moderate Speed
Urban/Suburban Maglev Vehicle as a Function of Speed

Basis = Same As Table 1, except 60 passenger Vehicles, & 200 KW(e) I^2R Power

Speed (mph)	Air Drag Power KW(e)	I^2R Drag Power KW(e)	Total Drag Power KW (e)	Total Drag Power/LSM Eff KW (e)	Energy Per Passenger Mile kWh(e)/PM	Energy Cost/PM $/PM	Energy/PM MJ/PM	Energy for Auto MJ/PM	Auto Gas Cost/M $/P
150	465	200	665	740	0.082	$0.008	0.29	7.0	$0.20
100	140	200	340	380	0.063	$0.006	0.23	ditto	ditto
75	66	200	260	240	0.064	$0.006	0.23	ditto	ditto

Table 3

Propulsion Power and Energy Requirements
For Maglev People Mover

Passenger Capacity Average Speed	30 30 mph
I^2R Drag Power [100% LSM Eff]	100 KW(e)
I^2R Drag Power [90% LSM Eff] Kinetic Energy of Vehicle [10,000 kg, 30 mph]	110 KW(e) 900 Kilojoules
Air Drag Power	Negligible
Nominal Travel Distance and Trip Time Nominal Station Stop Time	500 meters & 40 seconds 60 seconds
Average Speed Including Station Stops	12 mph (5.4 m/sec)
Energy Consumption Per Passenger Mile with Full Recovery of Kinetic Energy	
1. Levitated @ station	0.30 KWH/PM
2. Not Levitated @ station (mech.support)	0.12 KWH/PM
Energy Consumption Per Passenger Mile With No Recovery of Kinetic Energy	
3. Levitated@Station	0.33 KWH/PM
4. Not Levitated@ Stations (mech. Support)	0.15 KWH/PM

Figures

Tables