Maglev technology could rebuild U.S. transportation

Our collapsing transportation could be on the road to recovery if we invested in basic infrastructure such as magnetically levitated transport, reports Marsha Freeman.

For the past fifteen years, the United States has invested virtually nothing in maintaining, much less upgrading, the transportation systems that are prerequisite for the functioning of any economy. No new airports have been built, while air transport delays cost air carriers and passengers more than $5 billion per year. Tens of thousands more miles of railroad track have been abandoned. Highway congestion has reached crisis proportions, and cities' and states' resources to improve the situation are limited. In 1975, the U.S. Department of Transportation ceased funding the next-generation transportation technologies which would have averted this crisis. Promising work in developing magnetically levitated transport systems—known as maglev—was abandoned, using the excuse that it would "cost less" to improve existing rail lines, such as the bankrupt Penn Central-turned-Amtrak system in the Northeast corridor.

During these past 15 years, the Germans and Japanese have each invested about $1 billion in maglev technology, and have built short-distance, passenger-bearing demonstration systems. There is no doubt that the window of opportunity for the United States to participate in developing, building, and deploying this transport technology in the future is at most just the next few years: Over this decade of the 1990s, both Japan and Germany plan to build commercial-scale maglev systems at home, and, if they can, export the technology to this country.

Both the U.S. scientists who originated the concepts and basic ideas in the 1960s for maglev and who hold the patents, and others who are aware of the revolutionary potential of maglev, have watched with increasing frustration as the U.S. abandoned its lead in developing this advanced superconducting transport technology. But in the past few years, transportation has so deteriorated—e.g., footage of collapsing bridges that appears on the evening news broadcasts—that even some of the worst "cost-efficiency" fanatics in Washington have begun to realize this nation must replenish its stock of transport infrastructure.

The rub, of course, is the overused refrain, "But, where will the money come from?" The Bush administration has proposed that any investment in transport come from new taxes, euphemistically called "user fees" (see *EIR*, March 23, 1990, p. 66). The assumption is made that the federal government does not "have the money" to rebuild collapsing infrastructure.

More recently, however, a number of proposals have been made in legislative form to finance the commercial development of new surface transport technologies, including high-speed rail and maglev. Rather than debate from which pot the money should come, it is more important to force a return to the idea that it is the federal government's responsibility to provide the infrastructure required for the growth of the physical economy. Without aggressive federal programs for transport, energy, and water development, the United States is eliminating the possibility of returning to the status of a great industrial power.

New York Senator Daniel Patrick Moynihan (D) has made great public fanfare out of the fact that the $60 billion-plus surplus annually accumulating in the Social Security Trust Fund is being used by the Bush administration to reduce the federal government's operating deficit, to help make it appear as if the administration is within the irrational Gramm-Rudman deficit reduction guidelines. What Moynihan has proposed, instead, is that payroll taxes for Social Security be cut to eliminate the large surplus. At the same time, Moynihan has promulgated separate pieces of legislation and various schemes to both establish a National Infrastructure Corp. and to finance maglev development from the pension funds of government workers. Obviously, pension funds, as well as Social Security and other so-called surpluses, such as the Highway Trust Fund, would be better spent financing transport and other infrastructure, than being funneled into the Treasury to defray the debt-bloated federal deficit.

But where the money comes from is, at best, secondary. Rather than obfuscating the real problems with endless proposals on how to finance what is desperately needed, the federal government must return to a policy of providing low-interest, long-term credit for federal and local governments, as well as such credit and investment tax benefits to private industry, while drying up financial resources for speculative "investments."

But what, free-market fanatics will ask, is the "cost-benefit?" Any significant improvement in infrastructure increases the productivity of the economy as a whole. Transportation, for example, can comprise up to one-quarter of the cost of any product. Increases in productivity through new technology, can, therefore, cheapen the cost of all goods, throughout the entire economy. Like the postal system, transport itself may "lose money," but it creates the conditions through which all other economic activity is made possible.

Over the last century, this nation crossed its interior with railroads, highways, and waterways, and created links through the seas and the air with the rest of the world's economy. Over the next decade, we must have a leap-frog advance, from fossil fuel-based transport to the most efficient, energy-dense technologies for the 21st century. One of these is magnetic levitation.

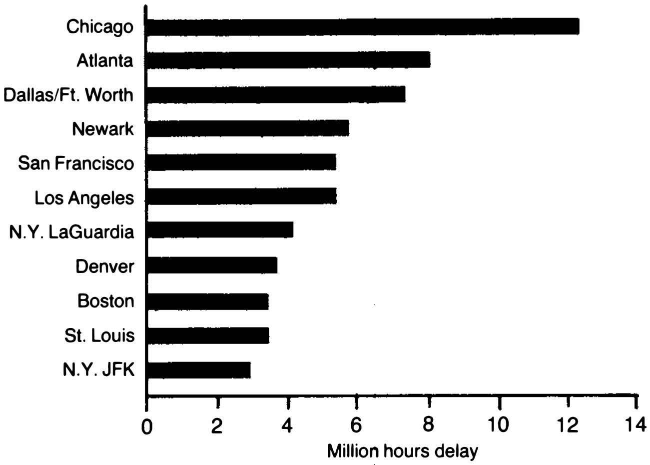
Electromagnetic flight

In 1912, French engineer Emile Bachelet levitated and propelled a model vehicle using the basic magnetic principle that forces of like polarity repel, and those of opposite polarity attract. In the 1960s, considerable research into designing full-scale transport vehicles making use of this simple idea was being carried out in the United States, Canada, Japan, West Germany, England, and Romania. But in 1975, the federal role in developing high-speed maglev in the United States ended.

Magnetically levitated systems are often referred to as "wheel-less trains," but actually they are more akin to flight. Because there is no contact between the vehicle and the guideway underneath it, the major parameters effecting the performance of the vehicle are aerodynamic. The vehicles must be designed, as are airplanes, for minimal aerodynamic drag. Therefore, they will be manufactured by aerospace companies, not rail-car builders.

FIGURE 1

Airports exceeding 3 million hours of passenger delay in 1987



The crisis in U.S. transportation is made clear from the millions of hours wasted by passengers and air carriers each year. Even five years ago, the Federal Aviation Administration estimated $5 billion was lost annually through such delays.

Using an electromagnetic propulsion system, along with magnetic levitation, a vehicle can maintain a constant *rate of acceleration*. Any other conventional transport system, such as rail or automobile, can accelerate up to a certain speed, and then must expend energy just in order to maintain that speed against the friction of the rail or road. But with maglev, since friction is eliminated and the vehicle can continue to accelerate at a constant rate: The longer it travels, the faster it can go.

The force of acceleration at airplane takeoff is approximately one g, or the forward thrust of the force of gravity, 32 feet per second squared. At a rate of acceleration about half that, a maglev vehicle would be accelerating at about 500 miles per minute. On a 3,000 mile trip across country, the vehicle would accelerate for 10-12 minutes, then cruise at 6,000 miles per hour for about 15 minutes, and then decelerate for another 10-12 minutes. The entire trip would take less than an hour! It takes time to build up speed and the vehicle could not be accelerated at a rate that would make passengers uncomfortable, and therefore, maglev is not significantly faster than wheel-on-rail trains for short distances. The farther it travels, the more time for acceleration, and hence, the faster maglev can go.

The top speed range for most steel-wheel-on-rail train systems is between 125-185 miles per hour (mph), because track alignment must be nearly perfect for a train to safely run at such relatively high speeds and difficulties arise from the continuous transmission of power through rail-wheel contact at high speeds. The Japanese Shinkansen ("Bullet") train line is closed down every day between midnight and 5 a.m. so 1,000 workers can check and realign the rails. Maintenance costs are, therefore, quite high.

Such high-speed wheel-on-rail systems are efficient for traffic in heavily populated regions, when the distance between cities is less than a few hundred miles, and trips are less than two hours, such as in Europe and Japan. But in the United States, air travel has exploded over the past decade, largely because the distances businessmen and others must travel is so great. At the same time, average population-density is considerably lower than in Europe or Japan.

The travel range in which 300 mph maglev systems could make a substantial contribution to rational transport is in the area of a 100-600 mile air or automobile trip, which in the United States includes inter-city travel throughout the congested East Coast corridor, throughout the states of Florida, Texas, and California, and between cities of the industrial Midwest. In these regions, levels of airport traffic have already surpassed the limits of civilized transport. **Figure 1**

Argonne National Laboratory

A chemist at Argonne National Laboratory uses liquid nitrogen to help cool a candidate material for higher-temperature superconductivity. Materials that stay superconducting up to 73°K above absolute zero can be cooled with liquid nitrogen, rather than less efficient liquid helium.

illustrates the severity of the problem. Maglev promoters have pointed out that if this technology could reduce the $5 billion-plus cost of airport delays suffered by passengers by even 30% over each of the next 20 years, the savings would pay for more than 2,000 miles of maglev infrastructure.

Highways are overcrowded and dangerous, and passenger rail transport has nearly disappeared. Magnetically levitated systems could provide quick, clean, energy-efficient connections for people, and even freight. In the longer term, vehicles placed inside evacuated tubes, where air resistance would not limit speed, could cross the nation in less than an hour.

In addition to its inherent advantages over conventional high-speed rail, electromagnetic flight will require the development of wholly new technologies, which will spin off into other industries and help propel the U.S. economy into the 21st century.

Basic principles of maglev

To levitate an object, either of the basic principles of magnetic attraction or magnetic repulsion can be employed, and both are being developed for maglev. Attractive maglev, also called electromagnetic suspension (EMS) **(Figure 2)**, requires placing an electromagnet underneath the carriage of the vehicle. The non-contacting guideway is made of an electrically conducting material, such as ferromagnetic steel, which is placed below the magnets on the vehicle. The vehicle is attracted to and is pulled up toward steel rails fixed to the guideway. If the attractive magnetic force should fail, for example from a power outage, the vehicle would come to rest on the guideway. All attractive maglev systems to date have used conventional iron-core magnets with copper coils.

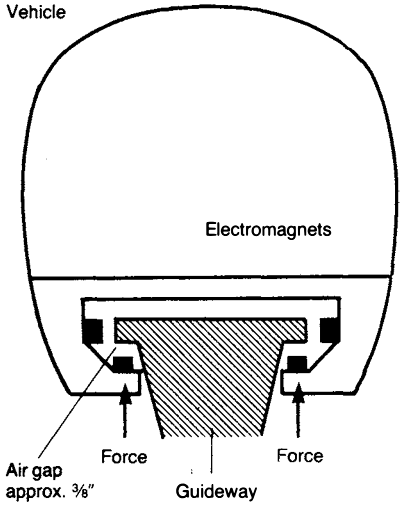
One important characteristic of attractive maglev is its inherent instability. Because of the relatively small magnetic field strength obtainable with iron-core magnets, there is only a small gap between the vehicle and the guideway. Typically, this air gap is less than an inch for a practical system, and hence produces very little tolerance for fluctuations caused by gusts of wind, passenger movements during travel, rail misalignments, and debris on the guideway. As in wheel-on-rail travel, the guideway must be maintained in nearly perfect condition. If the vehicle, for instance, moves slightly up toward the guideway and thus reduces the air gap, the attractive force increases, and the magnet on the vehicle is pulled even closer to the rail. No natural force is exerted to automatically restore the vehicle to its equilibrium position. Controlling the air gap in attractive maglev systems, therefore, requires continuous monitoring, and the magnetic attraction must also be continuously adjusted. The energy used in the feedback circuits required for stabilization and the magnetic drag increase with the vehicle speed.

From the beginning of research into maglev technology, it was recognized that repulsive maglev, or electrodynamic suspension (EDS) would be more stable than EMS. This

FIGURE 2

Attractive and repulsive maglev

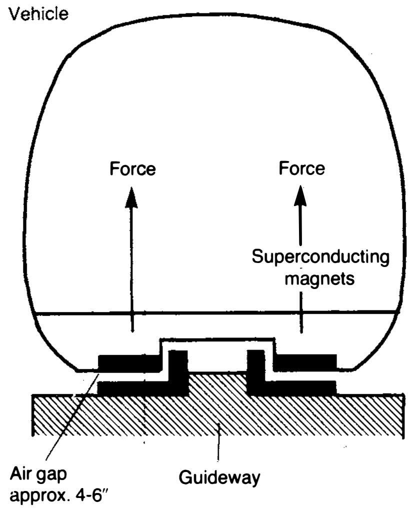
Electromagnetic maglev (attraction)



System: Germany's Transrapid 07

Electromagnetic, attractive maglev (left) uses conventional magnets aboard the vehicle which are attracted to a ferromagnetic guideway. This design creates a small air gap between the vehicle and the guideway of only a fraction of an inch. On the right is the superconducting, repulsive maglev design. Here, the magnets onboard the vehicle interact with induced magnetic fields from eddy currents produced in a light-weight aluminum guideway. The air gap is greater, and the vehicle is inherently stable.

Superconducting maglev (repulsion)



System: Japan's Linear Express ML-002

is due to the overall configuration of the magnetic fields generated, and the force of gravity, which provides a natural correction to any variations from the repulsive magnetic levitation, pulling the vehicle back toward the guideway.

The problem designers faced was to generate magnetic fields strong enough to lift a multi-ton transport vehicle, with magnets light enough to be carried onboard the vehicle—something which conventional magnetic systems could not do. Even in the 1960s when repulsive maglev was first proposed, however, the solution was at hand.

In 1908, Kamerlingh Onnes, working at the University of Leyden in Holland, succeeded in liquefying helium by achieving a temperature of only 4.2° Kelvin, or above absolute zero, for the first time. Up until that time, 20.3°K, which is the boiling point of hydrogen, was the lowest temperature ever maintained experimentally.

Three years later Onnes discovered the phenomenon of superconductivity, while exploring how far the electrical resistivity of a pure metal would decrease as the temperature dropped. He found that some materials brought down to 4.2°K exhibited *no* resistance to an electrical current—the current, once established, continued to flow unimpeded and appeared to be capable of persisting forever, because no resistance meant there was no loss of energy. It has been estimated that superconducting magnets for maglev will only have to be "recharged" after about 400 hours of use, or every two weeks, if the vehicle ran continually. Electromagnets require a continuous input of current to create the magnetic fields.

The importance of the discovery of superconductivity is revealed in the following comparison: A conventional 12 gauge copper wire cannot carry a current greater than 20 amperes because resistive energy loss and heating would melt the copper. A comparable wire of a superconducting alloy, such as niobium-titanium, can carry a current of 50,000 amperes, if kept at the temperature of liquid helium. Since there is no energy loss, once the magnet is energized, it does not require a continuing supply of electricity.

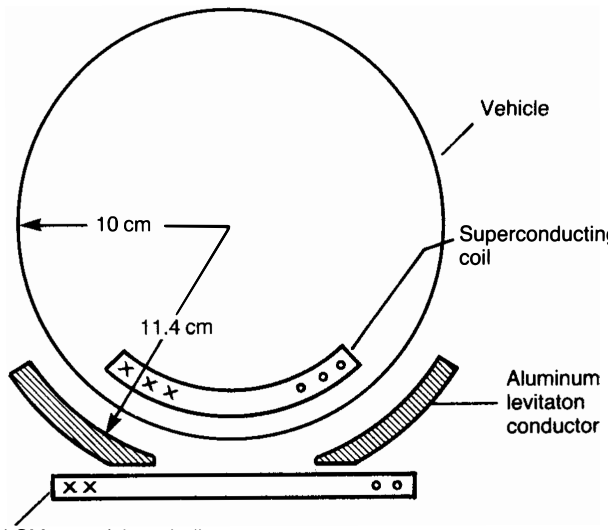
In a repulsive maglev design, superconducting magnets onboard the vehicle generate a magnetic field that interacts with a non-magnetic, but electrically conducting, light-weight aluminum guideway. The motion of the magnetic field over the guideway creates small electrical eddy currents, which, in turn, create a secondary magnetic field. This induced field has the same polarity as the field generated by the onboard superconducting magnets, because it has the same directionality, and repulsion results from the interaction of the two magnetic fields. Test vehicles have attained an air gap of up to 7 inches using superconducting magnets.

Since the *motion* of the superconducting magnet over the guideway is what creates the magnetic field, the vehicle must be moving in order for it to be levitated. Sufficient force is created for levitation at a speed of 20-30 mph. Until that speed is attained, the vehicle would be supported by wheels, similar to an airplane's landing gear. After liftoff, the wheels can be retracted to reduce aerodynamic drag.

The one-foot air gap between the vehicle and the guideway provides improved safety, allows flexibility for banking on curves, and eliminates the need to maintain a nearly perfect guideway. The gap will also make the system less sensitive to weather problems, such as rain, snow, or ice.

The repulsive or dynamic maglev is inherently stable,

FIGURE 3
Magneplane design



The MIT Magneplane, tested at 1/25 scale in the 1970s, used onboard superconducting magnets for levitation, propulsion, and guidance. This promising research was ended in 1975, when the government stopped funding maglev development.

because if the vehicle is disturbed by wind gusts or other movements and pushed closer to the guideway, the repulsive force would increase, which tends to push it back to its original position. If there were any anomalous increase in repulsive force, it would be counterbalanced by the gravitational pull of the vehicle back toward the guideway. The magnetic field interactions do produce electrodynamic drag, which is overcome by the propulsion system. Drag reaches a peak at a relatively low speed, depending upon the track thickness and vehicle design, and then diminishes when the guideway becomes electrically saturated, unlike aerodynamic drag, which continues to increase with speed.

Superconductivity for propulsion

The best method for propelling the maglev vehicle forward also makes use of superconductivity. Two types of rotary electric motors "unwrapped" into linear structures have been considered. The most promising design, using superconducting magnets aboard the vehicle, is a linear synchronous motor (LSN). In the Magneplane design, developed and tested in 1/25 scale at the Massachusetts Institute of Technology in the mid-1970s, the same superconducting magnets on the vehicle were used for levitation, guidance, and propulsion (see **Figure 3**).

For the LSM, coil windings are placed in the guideway, representing the non-rotating stator windings of the motor. The coils in the guideway are excited with an alternating current activated in only small sections at a time, coordinated with the approach of a vehicle (see **Figure 4a**). The current in the guideway is not transmitted to the vehicle. It produces an alternating magnetic field, or standing magnetic wave, and only a relatively weak current is needed in the guideway. The vehicle "rides" the electromagnetic wave, similar to the way a surfboard rides the waves of the ocean. The magnetic field created by the three-phase alternating electrical current in the guideway attracts the vehicle and pulls it toward it (**Figure 4b**). Then, when the vehicle is directly overhead, the direction of the current is changed and in that instant there is effectively neither an attractive nor repulsive interaction. But as the current changes direction, and the vehicle is moving forward to the next section of excited guideway, a repulsive force is created, pushing the vehicle along from behind. The vehicle moves in coherence with the alternating magnetic field.

The sequential energizing of guideway sections, called "blocks," requires a network of wayside power substations connected by power transmission lines and control cable switches that turn each block on and off. If the linear synchronous motor used a less powerful conventional copper coil magnet, it would require a high-voltage guideway. Large currents generated by the onboard superconducting magnets make the LSM feasible for maglev.

Higher-temperature superconductors

The maglev systems designed in the 1970s, which should be scaled up and demonstrated as quickly as possible, were designed before there was experimental evidence that material for magnets could be kept superconducting at much lower than the 4.2°K required for the niobium-titanium low-temperature superconductors that are now in use.

At a press conference in Houston on Feb. 16, 1987, Professor Paul Chu from the Texas Center for Superconductivity, University of Houston, announced that he had succeeded in producing a material that was superconducting at 93°K. New higher-temperature superconducting materials will allow the production of lighter and more reliable magnets, which will decrease the cost of maglev systems.

But scientists and engineers developing maglev technology have made clear that the higher-temperature superconductors are an *enhancing* technology for maglev, *not* an enabling technology. It is likely that the demonstration maglev systems of the 1990s will not use these higher-temperature materials, but they will probably be commercially available by the time large-scale, inter-city maglev transport systems are under construction.

A major advantage of the higher-temperature superconductors (HTSC) is the reduced weight of the magnets and reduced cryogenics to keep them cold, which could result in up to a 9.5% reduction in energy use (see **Table 1**). These new materials could reduce the vehicle's weight by as much as two tons, decreasing the energy required for both levitation and propulsion. The net effect is approximately a 3.2% decrease in propulsion power at a cruising speed of 300 mph. At lower speeds, where the ratio of electromagnetic drag to aerodynamic drag is higher and the ratio of lift to drag is lower, the effect of weight reduction is substantially greater.

Liquid nitrogen requires at least 30 times less energy to remove a given quantity of heat energy at 77°K than does liquid helium at 4°K, so onboard energy consumption for the magnets should be significantly reduced. Nitrogen's heat capacity is such that onboard liquefaction may actually not be required.

The commercial development of higher-temperature superconductors has been seen by the government as a research and development priority for American industry. The Council on Superconductivity for American Competitiveness (CSAC) was established in 1987 as a national organization for leaders in industry, government, and academia, with a primary mission to accelerate the commercial application of superconductivity throughout a range of applications. The CSAC board of directors has established a MAGLEV 2000 Task Force responsible for speeding up the development of a domestic maglev industry to design and build a superconducting system in this decade. It is recognized that maglev is an excellent potential market for the new superconducting technology.

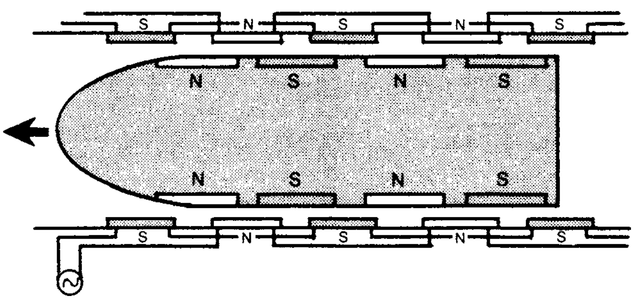
In addition to the fact that commercial maglev systems will require the mass production of magnets, which will push the state of the art in fabrication techniques, the threshold design requirements for the magnets will be less demanding than they will be for magnetohydrodynamics, fusion energy, magnetic motors and generators, ship propulsion, transmission lines, magnetic energy storage, and magnetic separation applications.

Dr. Gregory J. Yurek, president and chief executive officer of the American Superconductor Corporation testified on behalf of the MAGLEV 2000 Task Force on March 21, 1990 before the Senate Commerce, Science, and Transportation Subcommitte on Surface Transportation. "About 30 years ago, President Kennedy addressed a Joint Session of Congress to unveil his dramatic program to land an American on the Moon," Yurek stated. "America at that time was faced with an international competitiveness challenge, one with both political and technological implications. I would submit that today we are confronted with an equally daunting challenge—building from scratch a world-class, competitive maglev industry in the United States. Meeting this challenge will require the commitment of substantial economic and technical resources. Without this commitment, we could wit-

FIGURE 4

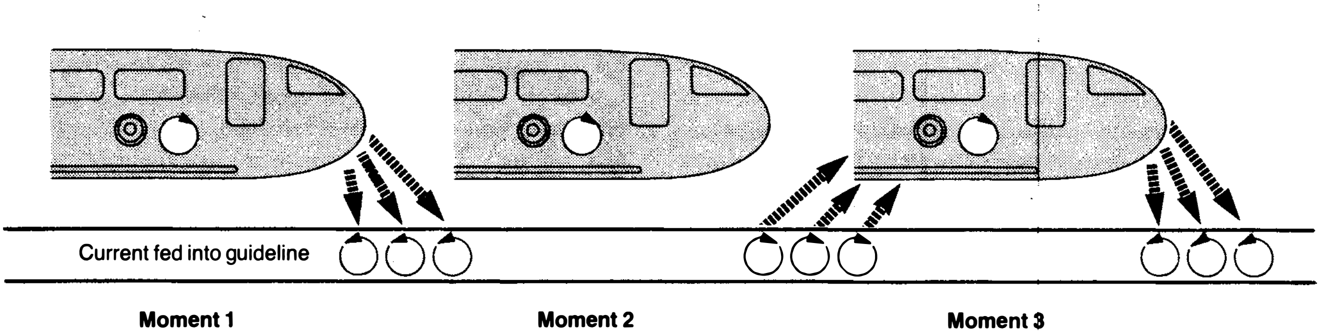
How a linear synchronous motor propels a maglev vehicle

(a)



The Japanese MLU 001 vehicle is propelled by a linear synchronous motor. The polarity of the coils in the guideway is alternated, and the magnet on the vehicle is attracted by the guideway coil of opposite polarity ahead of it, and repulsed by the same polarity immediately behind it.

(b)



This pictoral representation shows the change in the direction of the guideway current at Moment 2, when the vehicle is directly overhead. In Moment 3, the vehicle is both pushed from behind, and pulled from the front.

TABLE 1

Potential effects of weight reduction due to use of HTSC magnets

Item	Low-temperature superconductivity	High-temperature superconductivity
Weight (lb)		
Levitation magnets and cryostats	2,310	1,617
LSM magnets and cryostats	11,088	7,762
Vehicle suspension and structure	14,872	13,726
Magnet shielding	3,498	2,625
Subtotal	31,768	25,279
Total vehicle, inc. 100 passengers	63,360	57,321
Performance at 300 mph		
Aerodynamic drag (ton)	3.26	3.26
Lift-to-drag ratio	21	21
Electromagnetic drag (ton)	1.52	1.37
Net drag (ton)	4.78	4.63
Propulsion power (MW)	5.67	5.49

ness yet another American-invented technology to be commercially exploited by our foreign competitors."

Many local and state communities are now considering high-speed rail and maglev technology to alleviate the unbearable congestion in their transport systems. There is no question that any such investment will require federal government support, either directly, or at least indirectly by making available low-interest, long-term credit for investment. Some have suggested that the West German Transrapid technology be imported, to save time in developing the maglev technology and a U.S. industry to produce it. Such an approach would not really save any time; but it would circumvent the development of both a new transport system, and also an array of technologies which will have widespread applications in industry.

The United States has watched for 15 years as other nations developed magnetic levitation technology to the point of commercial introduction. We still have the time to leap ahead into the most advanced technologies, while we provide the transportation for a growing economy.

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