Maglev Energy Storage and the Grid

By

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MAPS Abstract

A new approach, the MAPS (MAglev Power Storage) system, for the storage of large amounts of electrical energy, is described. MAPS uses magnetically levitated and propelled Maglev vehicles to transport heavy masses from lower to higher elevations. Electrical input energy from the grid is fed into the Maglev vehicle's magnetic propulsion system, which operates in the motor mode as it transports the heavy mass to a higher elevation. The input electrical energy is stored as gravitation energy of the transported mass at the higher elevation. To feed the electrical energy back into the grid on demand, the heavy mass is returned by the Maglev vehicle to the lower elevation. Its stored gravitational energy is transformed to electrical energy by the magnetic propulsion system as it operates in the generator mode.

MAPS is very efficient. Over 90% of the input electrical energy drawn from the grid and stored is returned to the grid on demand. A MAPS system can store thousands of megawatt hours of electrical energy at very low cost, in the range of 2 to 3 cents per KWH. MAPS has potential annual revenues of hundreds of Billions of dollars in the World market. MAPS is much more efficient and lower in cost than pumped hydro for electrical energy storage. Moreover, it does not have the environmental concerns and site limitations that pumped hydro has. Other types of energy storage, e.g. flywheels, batteries, superconducting magnetic energy storage (SMES) are much more expensive per KWH stored, and are not practical for storing the large amounts of energy that MAPS can.

Superconducting Maglev Systems are already operating in practical and reliable high speed passenger vehicles in Japan. The proposed SUMMIT program would engineer and extend Maglev technology for commercial energy storage at a facility in Nevada. The three year Phase 1 program will demonstrate the performance capabilities of a full-scale MAPS facility. The 2 year Phase 2 follow on program would demonstrate long term continuous running capability of the MAPS system.

MAPS systems can provide energy storage for 3 major applications:

- **Store power from highly variable wind and power sources**
- **Store power from baseload coal and nuclear power plants to meet peaking power demands that are now supplied by natural gas power plants.**
- **Store electrical energy to maintain grid stability in the event of accidents and/or sabotage to power plants, transmission lines, etc.**

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1. Why Electrical Energy Storage?

The US electrical grid is a technology marvel. It provides ample and reliable amounts of electrical energy to virtually every person, industrial, and commercial entity in America on demand, usually without problems, and at an acceptable cost. Long distance transmission lines interconnect many large power generation plants around the United States and Canada, with millions of users scattered across the country, transmitting many thousands of megawatts over distances of many hundreds of miles.

However, there are limitations and concerns about the US electrical grid. Electrical demand varies considerably and often rapidly with the time of day, day of week, and season. Baseload generating plants, e.g. coal fired and nuclear, cannot meet rapidly shifting demands, because their time response is too slow. To react to fluctuating demands, quick response peaking power plants, usually fueled by expensive natural gas, are used. Typically, about 20% of the annual kilowatt hours (KWH) consumed in the US comes from gas fired peaking power plants. The cost of this energy is substantially greater than the cost of power from coal fired and nuclear power plants.

That is now. The situation becomes worse if the US begins to shift away from coal fired power plants towards renewable wind and solar power sources. The outputs from wind and solar are highly variable and non-predictable. When the wind blows – which is typically only 30% of the time – the generated power may or may not be matched to demand. Sometimes there will not be demand for the wind power; other times there will be demand, but the wind isn't blowing.

Matching variable output will require new energy storage technologies. Pumped hydro storage is practical but has siting restrictions and major environmental concerns. Total US electrical generation capacity is 1 million megawatts, while the pumped hydro capacity is only 22,000 megawatts (1) – about 2% -- and it's unlikely to get much larger. Moreover, potential wind and solar power sources are often far removed from any possibility of a pumped hydro storage facility. Also, the output/input energy efficiency of pumped hydro is only about 70%, so a substantial fraction of the input power is lost (2). Compressed air storage in underground cavities is a recent technology development, but it too has limitations and concerns. One requires stable geologic conditions, and output/input power losses are substantial.

Pumped hydro and compressed air storage fall into the category of bulk energy storage, with the capability of storing many hundreds of megawatt hours at high, but still acceptable cost.

The other energy storage options – flywheels, batteries, hydrogen fuel cells, thermal, and superconducting magnetic energy storage (SMES) – fall into the category of micro energy storage. They are too expensive and too limited in capacity to store large amounts of electrical energy. They can play a very useful dynamic role, however, in helping to ensure that the various sections of the grid system connected together have uniform frequency and phase.

In addition to meeting time varying power demands and ensuring proper frequency and phasing in the grid, energy storage systems, particularly bulk storage systems, can provide insurance against grid failures due to accidents and sabotage. Several years ago, some trees fell during a storm in Ohio, disrupting electrical transmission capability. As a consequence of propagating failures, the US Northeast was blacked out for a substantial length of time. Sabotage is an even greater worry. It can be physical in nature – blowing up substations and/or transmission lines, attacking power generation plants, etc – or it can be cyber in nature – shutting down power plant controls, substation switches, etc.

Large scale, low cost bulk energy storage would greatly help ensure that accidents or sabotage would not shut down large sections of the US electrical grid, by providing electrical energy for extended periods of time to make up for the portions that were temporarily not working.

2. The US Electrical Grid – Current Status

Table 1 shows the installed US electrical generation capacity by type of generation, plus the amounts of electricity actually generated from the various sources. Figure 1 shows the actual amounts expressed as a fraction of the total actual generation.(3)

Table 1

Megawatts of Installed Electric Capacity and Megawatt Hours of Actual Electric Energy Generation Per Year for the United States as a Function of Generation Type.

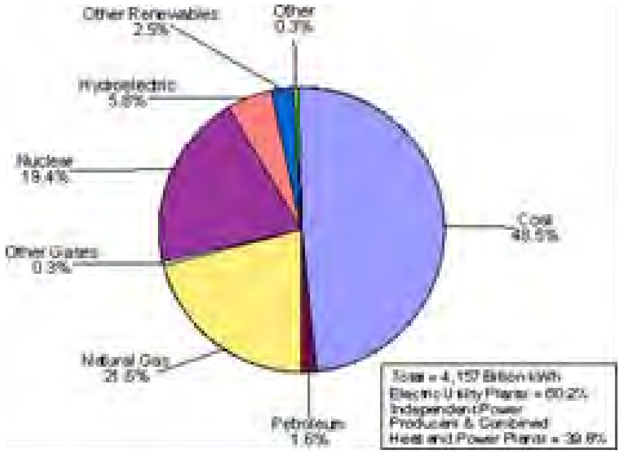
Basis: EIA 2008 Data (1,3)

Type of Generation	Installed Capacity (Megawatts)	Annual Electric Generation (Million Megawatt Hours)	% of Total Actual Generation
Coal Fired	337,300	1,996	48%
Natural Gas	454,611	883	21%
Nuclear	106, 147	806	19%
Hydroelectric	77,731	255	6%
Wind	24,980	55	1%
Solar	539	0.9	0.02%
Geothermal	3,251	N A	N A
Other	100,200 (a)	162	4%
Total	1,104,486	4,157	100%

(a) includes 20,355 megawatts of pumped storage

Figure 1

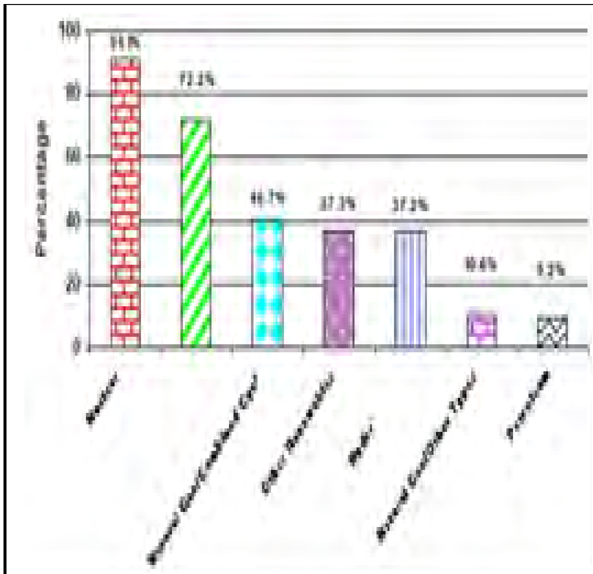
Source: Energy Information Administration, *Electric Power Annual 2007*.



- 76% Fossil Fuel (Coal, Natural Gas, Oil)
- 2% Wind & Solar
- 19% Nuclear
- 6% Hydroelectric

While natural gas generation capacity 455,000 megawatts is considerably greater than coal-fired generation capacity (360,000 megawatts), the actual amount of electrical energy generated is considerably less (883 million megawatt hours) than that for coal plants (1, 996 million Megawatt Hours). Figure 2 shows the capacity factors for the fraction of time that the plant actually operated for the various types of generation (4). Nuclear was highest, 91%, followed by 72% for coal, and 47% for natural gas.

Figure 2 Average Capacity Factor By Source



- 91% Nuclear
- 72% Coal
- 47% Natural Gas (Peaking Power)
- 37% Wind & Solar (Variable Supply)

Table 2, the levelized energy costs for California in 2007(5), illustrate the 2 main reasons that natural gas plants operate at a low capacity factor. The power that they produce is much more expensive than from coal and nuclear plants, so that they only operate when baseload plants cannot meet power needs during high demand periods. The second main reason is that natural gas power plants can increase/decrease output generation much more rapidly than coal and nuclear plants, so they can load follow much better.

Table 2

Source	Cost($/MWH)
Advanced Nuclear	67
Coal	74-88
Gas	313-346
Geothermal	67
Hydroelectric	48-86
Wind	60
Solar	116-312

If there were electrical storage systems that could be sited virtually anywhere with no environmental problems, that could store very large amounts of electrical energy at low cost per KWH, that were rapidly responsive, and that had high output/input electrical efficiency, there would be no need for natural gas peaking plants – baseload plants could supply all the power. Energy storage systems would meet the bulk of the peak power demands, amounting to approximately 1000 million megawatt hours of energy generation.

As one can see from Table 3, present energy storage systems cannot meet the peak power market presently held by natural gas peaking units. (6) Pumped hydro is the only substantial supplier, and its capacity is only a small fraction, about 4%, of the capacity of natural gas power plants.

Table 3

US Generation Equals 1,000,000 MW

Average Power Costs = 97$/MWH

Storage Type	Capacity (MW)	Storage Cost
Pumped Hydro	22,000 (US)	50 = 100
Compressed Air	400 (World)	N/A
Batteries	270 (World)	70-860
Flywheels, Hydrogen, SMES, etc. are Negligible		

Wind electric power generation is only a very small fraction of US and World generation, being about 1% of US total generation and 2% of World generation. The EIA

(Energy Information Administration) projection is that World generation from wind power will slowly climb to almost 5% of the World total by 2035 – a lot less than wind power advocates want and expect.

Because of the highly variable output and low capacity factor of wind power – the wind speed is only strong enough to generate power about 30% of the time, it is likely to remain at the few percent level unless a new large-scale, efficient, low cost energy storage system is developed. The present energy storage systems cannot meet the requirement needed for large scale implementation of wind and solar power sources.

3. The Maglev Energy Storage Concept

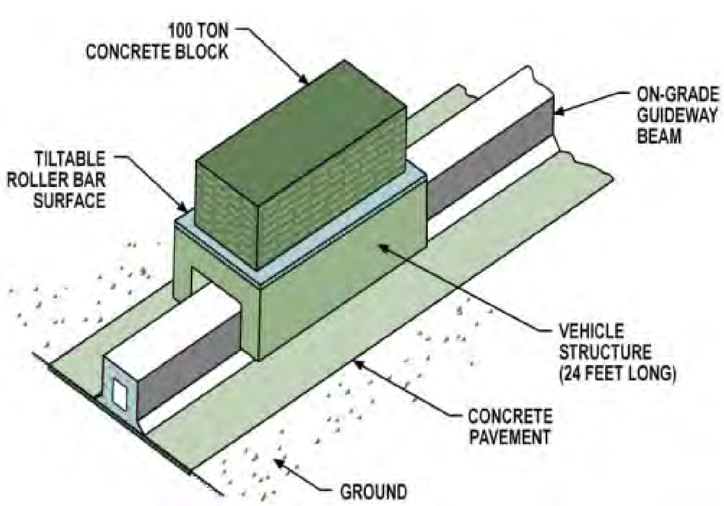
The MAPS (Maglev Power Storage) system stores electrical energy by using magnetically levitated and propelled vehicles to move heavy masses uphill. The levitated Maglev vehicles do not physically contact the guideway that they travel along, so that there are no mechanical friction losses. Maximum vehicle speed is moderate, on the order of 100 mph, so that air drag losses are small.

Moving a heavy mass uphill from a lower elevation takes electric power from the grid for the vehicle's magnetic propulsion system. The electrical energy used during the uphill trip is then stored as gravitational potential energy of the mass when it is unloaded at its designated location at the higher elevation.

To retrieve the stored energy of the heavy mass, it is then transported downhill by the Maglev vehicles whenever power flow to the grid is desired. During the uphill trip, the vehicle's magnetic propulsion system operates in the motor mode, converting input electrical energy to gravitational potential energy of the mass as it climbs to a higher elevation. During the downhill trip, the vehicle's magnetic propulsion system operates in the generation mode, converting the gravitational energy of the mass back to electric energy which is fed back to the grid.

Moving a 100 metric tonne mass uphill for 3000 feet altitude gain stores 250 kilowatt hours of electrical energy. More than 90% of this stored energy can be recovered and fed back to the electrical grid when the block is moved downhill.

Figure 3



For easy handling and rapid loading and unloading the heavy mass can be a large concrete block, as shown in Figures 3, 4, and 5. Figure 3 shows an isometric view of the Maglev vehicle moving a 100 tonne block along the MAPS guideway. Figure 4 shows a cross sectional view of a vehicle carrying the block, while Figure 5 shows it after the block has been unloaded. A detailed description of the MAPS System is given in the DPMT report, DPMT-14 (7)

Figure 4

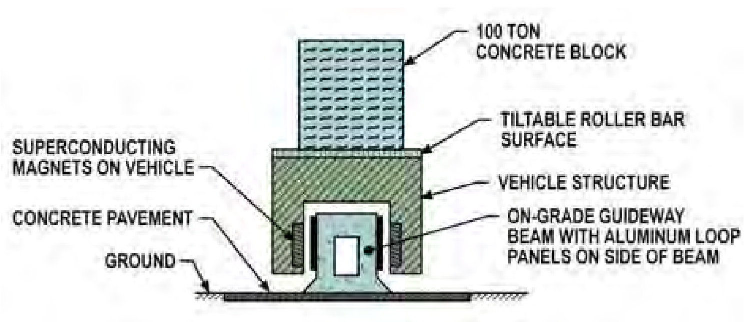


Figure 5

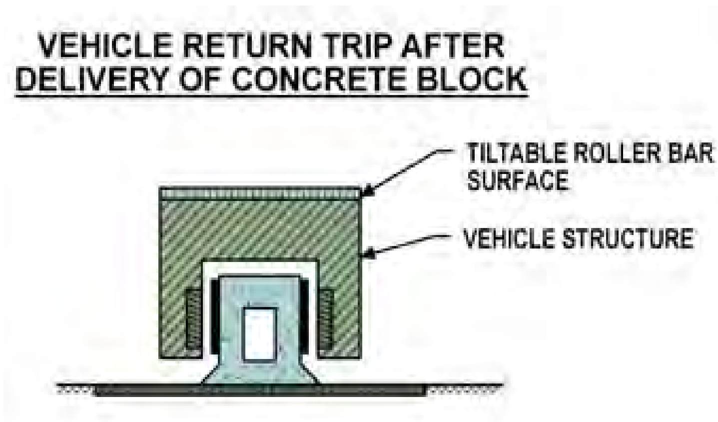
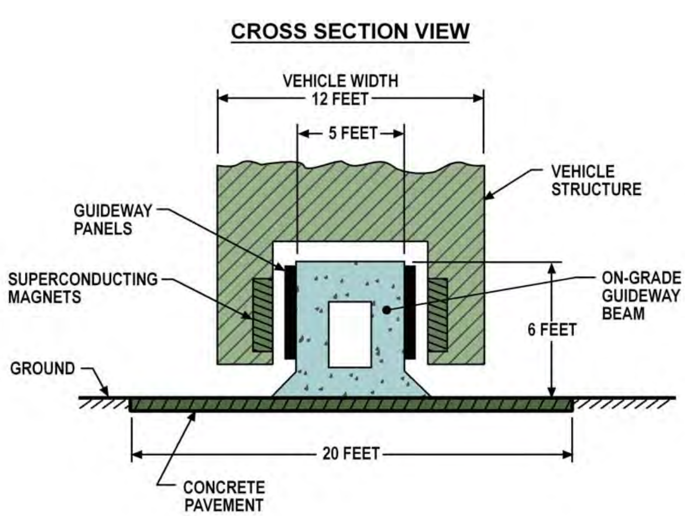


Figure 6



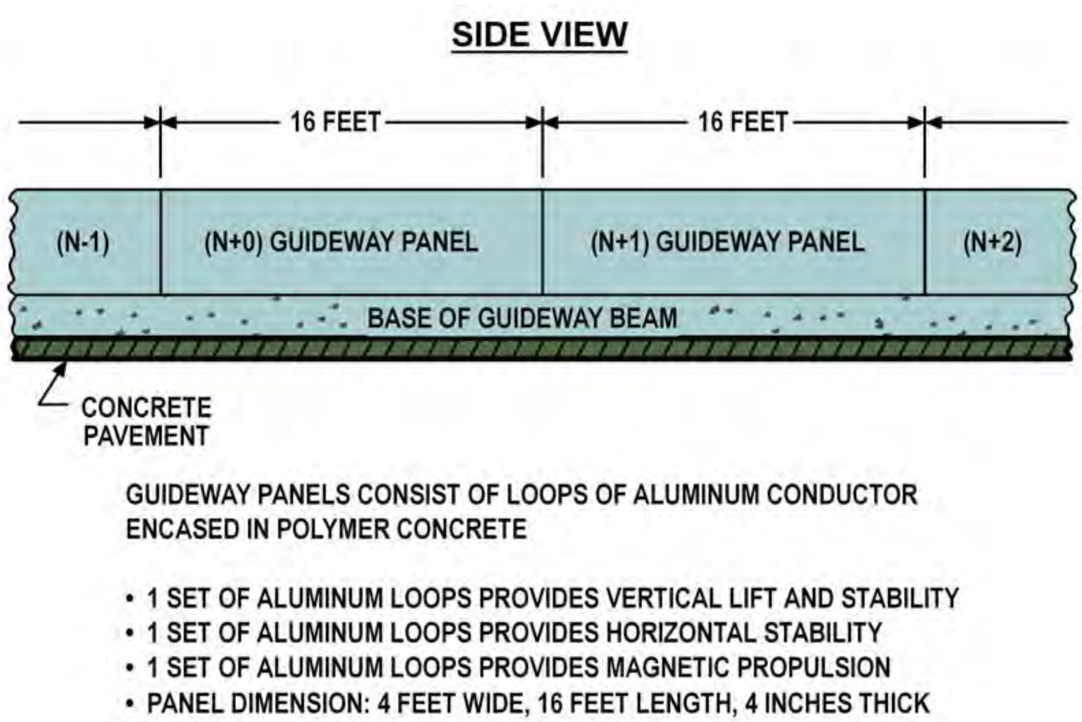
The concrete block can be a solid mass of concrete, or a concrete box filled with heavy rocks. The second option would be cheaper, but either is affordable. At 130 dollars per cubic meter for concrete (100$ per cubic yard) and a density of 250 kg per cubic meter, the capital cost of a 100 tonne solid concrete block would be only about 5000 dollars. Amortized over a 30 year period with 1 storage per day, the cost per KWH stored by the block would be only 1/5th of a cent. The amortized cost of a concrete box filled with rocks would be even smaller, less than 1/10th of a cent per KWH.

The MAPS guideway shown in Figure 6 is a simple concrete box beam located on a concrete highway type pavement. The nominal width of the pavement is 20 feet, a bit less than the standard 2 lane highway. The stresses on the pavement when the Maglev vehicle passes a given point are much smaller than highway pavements experience, because the load is spread out over a much larger area. With an 80,000 pound 18 wheeler, the point loads on a highway pavement under the wheels are each on the order of 20,000 lbs per square foot.

A MAPS Maglev vehicle carrying a 100 metric tonne load plus its empty weight of 10 tonnes, for a total weight of 110 tonnes, would have a pavement load of only about 2000 pounds per square foot, a factor of 10 less than a highway truck. The Maglev vehicle is supported by the magnetic interactions between the superconducting magnets that are located along the length of the vehicle and the guideway panels on the sides of the box beam (Figure 7).

The guideway panels contain 3 sets of aluminum loops plus a set of iron plates at the top of the panel. When a Maglev vehicle passes the panel, the iron plates interact with the superconducting magnets on the vehicle, providing a portion of the magnetic lift force. One of the three sets of aluminum coils in the panel carries current induced by the superconducting magnets as they pass the panel, providing additional vertical lift force. The combination of iron plates and set of Figure of 8 null flux aluminum loops support the vehicle in the vertical direction. The support is inherently vertically stable – if the vehicle is displaced upwards from its equilibrium suspension height, the magnetic lift force

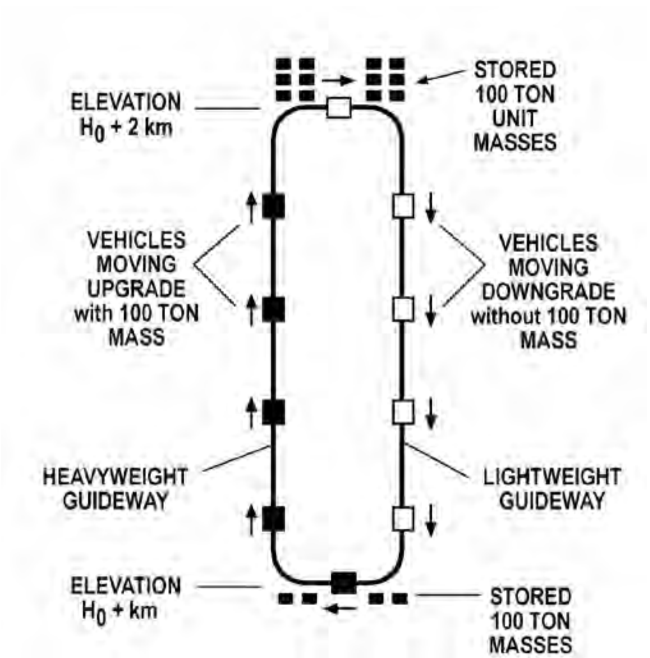
Figure 7



automatically decreases, causing it to move downwards to the equilibrium point. If the vehicle is displaced downwards from its equilibrium point, the magnetic lift force automatically increases, causing it to move upwards to the equilibrium point.

The second set of aluminum loops in the guideway provides automatic horizontal stability. If the vehicle is displaced horizontally in either direction, left or right, from its center position on the guideway beam, force generated by induced currents in the second set of aluminum loops that push the vehicle back to its center position on the beam.

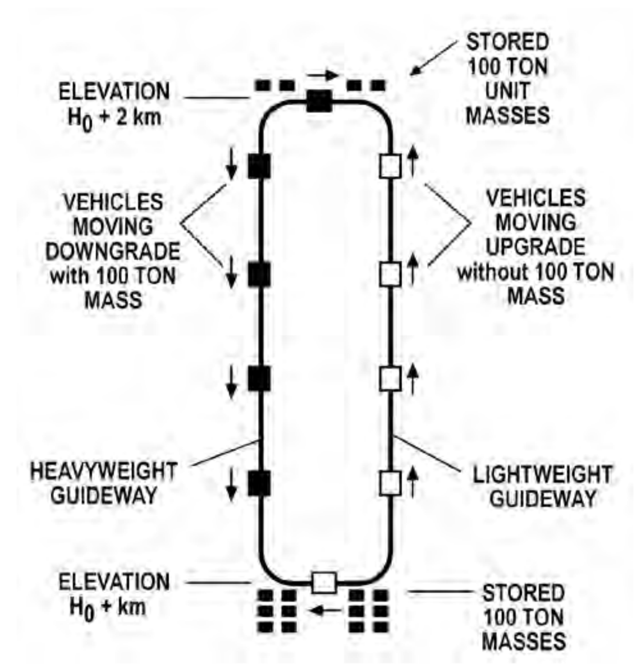
The third set of aluminum loops in the panels carries an applied AC current derived from electric power drawn from the grid. The AC current pushes on the DC superconducting magnets on the vehicle, magnetically propelling it along the guideway. The system can operate either in the motor mode, where the applied AC current propels the MAPS vehicle uphill, or downhill in the generator mode, where the powerful superconducting magnets generate AC power in the guideway loop circuit, which is then fed back to the electric grid.

<table>
<tr><th>Figure 8 MAPS, Energy Storage Mode</th><th>Individual Vehicle Can:</th></tr>
<tr><td>
</td><td>
• Make 20 Round Trips/Hour (Site Dependent)
• Store 40 MWH in 8 Hour Period
• Operates @ 30 MW Power Level</td></tr>
</table>

There is a DC/AC power conditioning link between the MAPS power system and the grid. 60 Hertz power from the grid is rectified to DC and then inverted to AC power at the proper frequency for the MAPS System.

As the MAPS vehicle accelerates, the AC frequency is increased – in effect, the MAPS propulsion system operates as a Linear Synchronous Motor. As the MAPS vehicles decelerates, the AC frequency decreases, and the vehicle operates as a Linear Synchronous

Generator. In the electric sense, MAPS operates very much like conventional synchronous motors and generators, except that the geometry is linear, not rotary.

Figure 9 MAPS, Power Delivery Mode	Multiple Vehicles Can:
	• Operate on Guideway at Same Time • Operate at Total Input/Output Power of 100's of MW • Stores 1000's of MWH

The synchronous nature of the MAPS magnetic propulsion system is very important.

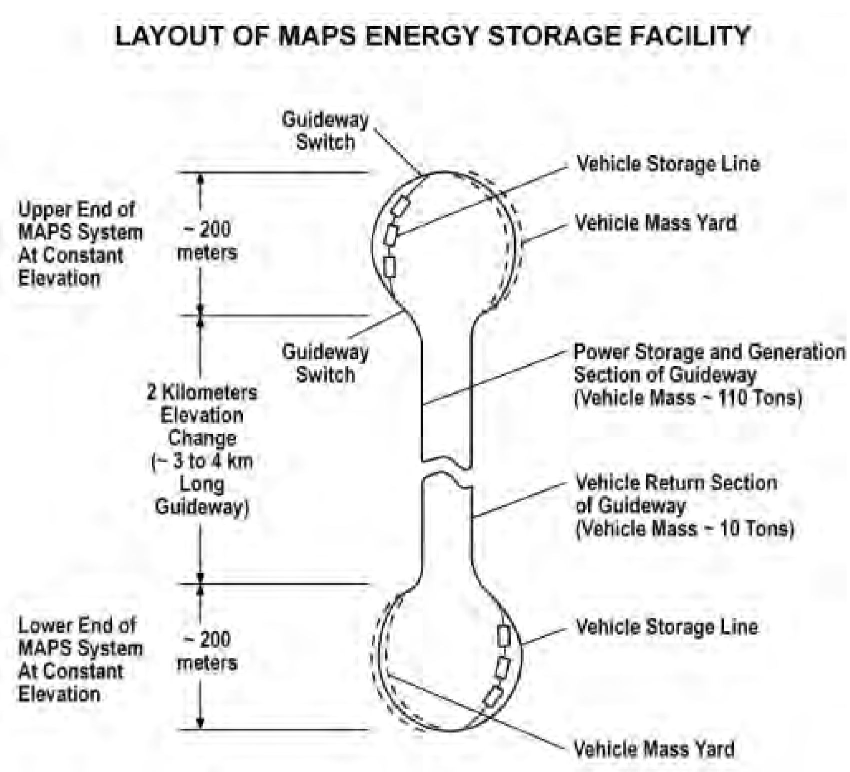
The vehicles are phase locked into the AC current wave as it travels along the guideway, with the vehicle speed controlled by the frequency of the AC wave. Variations in external force on the vehicle do not change its speed, only its phase relative to the AC current wave. In effect the MAPS vehicles travel much like a surfer on a water wave, with their speed being the same as that of the wave.

As a consequence, the distance between vehicles operating on a MAPS guideway will automatically remain constant, ensuring that collisions cannot occur. For high propulsion efficiency, the entire MAPS guideway is not completely energized – only those sections on which vehicles are currently operating. The length of each energized block is approximately 200 feet. As a vehicle leaves an energized block, the propulsion power is switched into the next block. Similarly, when the vehicles are running downhill in the generator mode, the output power is switched off from the block that the vehicle is leaving, and switched on from the next block.

Figure 8 illustrates the MAPS energy storage mode, in which multiple vehicles can operate on the guideway simultaneously. As each vehicle reaches the top of the uphill guideway, it unloads it 100 tonne block into a storage yard. The flat top of each vehicle has a set of roller bars on which the block moves. Movement can be achieved either by powering the roller bars, with their rotation providing the force required to move the block off of the vehicle, or by hydraulically tilting the upper surface of the vehicle, so that the block slides off onto a conveyer, also with roller bars, that moves the block to a designated location in the storage yard. The powered roller bar approach appears to be the most promising system, though the tiltable surface is also practical.

As an alternative to the roller bar conveyor system to move the concrete blocks in the storage yard, the unloading dock can transfer the blocks to the flat top surface of a wheeled vehicle that moves them to an appropriate location in the yard, where the block would sit on a concrete ledge. To receiving the block and bring it back to the loading dock for transfer downhill to generate power, the wheeled vehicle would simply slide under the sitting block and hydraulically lift it off its ledge onto the vehicle. The wheeled vehicle would then quickly move the block to the loading dock where a roller bar system would load it onto the Maglev vehicle. The storage yard would be paved like a highway, with a paved area equivalent to approximately a mile of 4 lane highway for a storage capacity of 1,000 megawatt hours.

Figure 10



Maglev vehicles move the 100 tonne blocks downhill. In the power storage mode, the vehicles travel in the clockwise direction on the guideway, while in the energy delivery mode, they travel counterclockwise. The left side of the guideway transports the fully loaded vehicles with their 100 tonne blocks both uphill and downhill, requiring a heavy weight guideway, with the right side of the guideway transports only the unloaded Maglev vehicles which are much lighter than the fully loaded Maglev vehicles, i.e., 10 tonnes versus 110 tonnes.

Multiple vehicles can travel on the MAPS guideway at the same time, either as individual units, or as consists of several vehicles coupled together. A single vehicles can make as many as 20 trips per hour, depending on the height it raises the 100 tonne block, e.g., 3000 feet, the angle of the guideway, e.g. 30 degrees, and the maximum speed it travels at, e.g. 60 meters per second (134 mph). The vehicles have to decelerate as they approach the upper and lower load/unload points, and accelerate back to maximum speed after they leave them.

At a maximum speed of 60 meters per second and a guideway angle of 30 degrees, an individual vehicle carrying a 100 tonne block is operating at 30 megawatts from the grid if it is storing energy and 30 megawatts to the grid of it is delivering energy. The power rating can be reduced if desired by operating at lower maximum speed. Similarly, if the guideway angle is less than 30 degrees the power rating will be lower.

Over an 8 hour period, an individual vehicles with 20 round trips per hour and an elevation change of 3000 feet would store 40 MWH. Using multi-vehicle consists; the amount of energy stored would be much greater. For example operating with 25 vehicles in the multi-vehicle consists, 1000 MWH could be stored/delivered over an 8 hours period, average input/output of 125 megawatts. Figure 10 shows an overall layout of the MAPS facility. There are switching sections at the top and bottom of the guideway to sidings where vehicles currently not in use can be stored. When required to handle increased power levels, either in the storage mode or the delivery mode, vehicles can be rapidly switched out from the sidings to handle the increased power level.

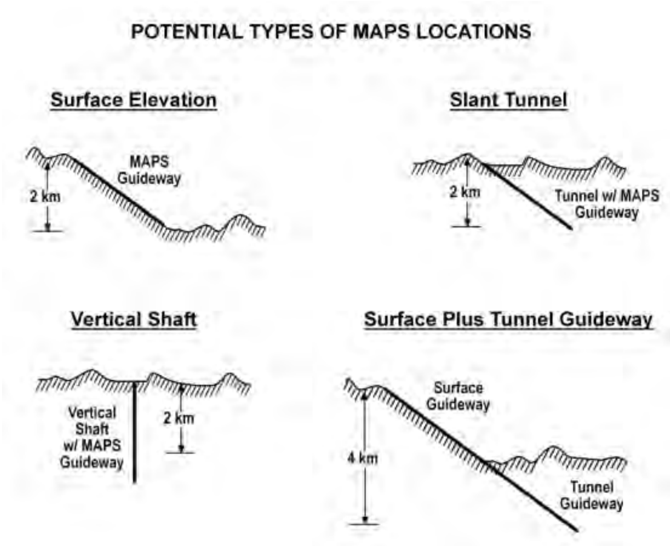


Figure 11

MAPS facilities can be sited at a very wide range of locations, in hilly and flat terrains. In hilly terrains, the MAPS guideway would ascend on the rising terrain from a lower elevation to a higher one. On flat terrain, the MAPS guideway could be located in slant tunnel (Figure 11) that descended several thousand feet. Tunnels in hard rock mines descend to a depth of 9,000 feet or more. In coal mines, with less stable rock, tunnels descend to depths as much as 3,000 feet. Alternatively, a vertical shaft guideway could be used, with the blocks stored underground in tunnels, i.e. “drifts” in mining terms, that lead off from the vertical shaft. In certain locations where a greater change in elevation is desired than is available from local hills, the guideway could combine a surface elevation rise with a slant tunnel (Figure 11).

With such a wide range of locations, and an equally wide range of storage capabilities, there is no single design for a MAPS facility. Table 4 gives an illustrative design for a 1000 MWH facility with a 3000 foot elevation change and is somewhat slower maximum vehicles speed of 1000 mph than the 134 mph capability. Because of the slower speed, vehicles make only 15 round trips per hour, not 20. MAPS capital and operating costs are derived from detailed design studies carried out for Maglev passenger and freight transport applications. Detailed cost analyses specific to MAPS designs remain to be done.

Table 4

MAPS Storage Capacity and Cost

Basis: 1000 MWH Storage Capacity Per Day 8 Hour Storage & Delivery Periods 100 Ton Storage Block (250 KWH/Block, 4000 Blocks) 3000 Foot Elevation Rise, 30 Degree Angle 100 MPH Maximum Vehicle Speed 15 Round Trips Per Hour Per Vehicle (50 Sec Load/Unload Time) 33 Vehicles (40 including Spares) @ 2 MS/Vehicle Capital Cost 90% Output/Input Efficiency ($100/KW(e) Power Equipment) 2.5 miles of One-Way Guideway 30 Year Amortization Period

Hardware Component	Capital Cost (MS)	Amortized Capital Cost ($.MHW)	Operating Component	Operating Cost ($/MWH)
Guideway & Storage Yard	30	2.7	Personnel	5.4
Vehicles	80	7.3	Maintenance	2.7
Power Equipment	12	1.1	Propulsion	
Concrete Blocks	20	1.8	Power (Purchased at 5 cents/KWS)	8.0
Handling Equipment	10	0.9		
Total	152	12.8		$16.1/MWH
		(1.5 cents/KWH)		(1.6 cents/KWH)
Total Cost/MWH = 12.8 +16.1 = $28.9/MWH = 3 cents/KWH for Illustrative MAPS System				

The largest cost component for MAPS is the cost of operating power for the MAPS facility, which is primarily the cost of propulsion power for the MAPS vehicles as they make their input and output runs. At an overall output/input electrical efficiency of 90%, with grid power purchased at 8 cents/KWH, the power cost component is about 0.8 cents/KWH or $8 per MWH.

An output/input efficiency of 90% corresponds to purchasing 1.1 KWH of power from the grid for every KWH that the MAPS facility delivers back to the grid. Using a pumped hydro storage unit with a output/input efficiency of 66%, 1.5 KWH of electricity would be purchased form the grid for every KWH delivered back to it. At a cost of 8 cents/KWH purchased from the grid, the cost of the power required to operate the pumped hydro facility would then be 0.5 X8=4 cents per KWH, or $40 per MWH – 5 times greater than the costs of power for MAPS.

The total storage cost for the illustrative MAPS design is then 2.9 cents/KWH ($29/MWH), including the amortized capital costs of the guideway and vehicles, blocks, and the handling equipment, plus the operating costs for power, personnel, and maintenance.

For the range of MAPS applications, depending on site conditions, power storage requirements, etc., the total cost for MAPS storage will be in the range of 2 to 3 cents/KWH ($40 to $30 per MWH). This storage cost will be well below the cost of power generation from wind and solar sources, and also well below the cost differential between power generated by baseload coal/nuclear power plants and the cost of peaking power from natural gas plants. Accordingly, MAPS can be used both for storing energy from renewable wind and solar plants, as well as storing power from baseload cost and nuclear power plants to meet peak power demands.

Finally, the presently estimated cost of the MAPS guideway is based on trucking pre-fabricated guideway beams to the construction site and placing them on a pre-poured concrete pavement, similar to the construction mode for the Maglev elevated monorail guideway for transport of passengers and freight. The guideway cost could significantly reduced by casting the concrete guideway box beam directly in place on the concrete pavement.

4. Status of Maglev Energy Storage Technology

MAPS uses superconducting Maglev technology, invented by Powell and Danby in 1996 (8). Based on their inventions, Japan has demonstrated that superconducting Maglev is a practical mode of transportation. Japan Railways 1st generation passenger transport system (Figure 12) is now operating in Yamanashi, Japan. The 20 mile long 2-way Maglev demonstration route has carried well over 50,000 passengers safely and reliably, with accumulated running distances of hundreds of thousands of miles. Japan Railways plans to incorporate the Yamanashi line into a 300 mile Maglev route between Tokyo and Osaka that will carry 100,000 passengers daily, with a trip time of 1 hour. The Japanese superconducting Maglev system holds the World speed record for ground transport, at 361 mph.

Figure 12 View of Japan Railways Superconducting Maglev Guideway and Vehicle System

Germany has developed a different 1st generation Maglev system, termed Transrapid, with a 1st generation system now operating in China. It uses conventional electromagnets on the vehicle, which are attracted upwards to iron rails on the guideway, levitating it. To overcome the inherent instability of the Transrapid system to maintain the ~ 1 centimeter gap between the vehicle electromagnets and the iron rails, it is necessary to rapidly servo control the currents in the windings on the vehicle's electromagnets, in a time scale of thousandths of a second.

In contrast, the superconducting Maglev System is inherently strongly stable, with magnetic restoring forces that automatically oppose any external force (e.g., winds, curves, etc.) that would act to displace the vehicle from its equilibrium suspension position. The gap between vehicle and guideway is much greater for superconducting Maglev than that for electromagnetic Maglev, typically ~ 10 cm vs. ~1 cm. The much larger gap enables the guideway to be built with less demanding construction tolerances, helping to reduce the cost of construction.

The German Transrapid System is not practical for MAPS, because the required electric power to operate its conventional electromagnets would be far too great if it were used to transport 100 tonne blocks uphill and downhill for MAPS energy storage. The superconducting magnets used on superconducting Maglev vehicles have zero electrical energy losses, and lift much heavier loads than conventional electromagnets. There is a small energy requirement for the refrigeration equipment of the cryogenic superconducting magnets, but this power requirement is tiny compared to the input/output power that the MAPS vehicles handle to move blocks uphill and downhill.

Following their 1966 publication of superconducting Maglev and their 1969 patent on it, Powell and Danby continued work on it in greater detail (8,9,10,11,12,13,14,15), including the superconducting Linear Synchronous Motor (16), in which a small AC current in a sequence of aluminum guideway loops magnetically interacted with the superconducting magnets in the vehicle to propel it along the guideway at a fixed speed determined by the frequency of the AC current. For their work on superconducting Maglev, Danby and Powell were awarded the Franklin Institute Medal for Engineering in April, 2000.

The 1st generation Maglev systems, while technically successful, have limitations that to date have prevented implementation of a large scale. Two factors are of particular importance in limiting their implementation, particularly in the U.S.

First, the construction cost of the guideway is very high, $50 million dollars or more per mile. This is much more than the cost of High Speed Rail (HSR) systems, which is on the order of 20 to 30 million dollars per mile. While Maglev offers shorter travel times than HSR, its advantages are not great enough to justify the higher construction cost.

Second, the 1st generation Maglev systems only carry passengers. While very useful in densely populated areas like Europe and Japan, passenger only systems are of less utility in lower population density large countries like the United States. In the U.S. the big transport outlays are for intercity trucks (over 300 Billion dollars annually), compared to intercity air passengers (60 Billion dollars per year) and intercity rail passengers (only 3 Billion dollars per year.) Passenger only systems in the U.S., whether they are Maglev or High Speed Rail, will require major government financing for construction and continued large subsidies for operation and maintenance. Because of America's very large governmental debt, both State and Federal, it is unlikely that major government financing is possible. To be implemented, Maglev routes will have to attract private investment. To achieve this, they must be profitable, with a relatively short payback time on invested capital, e.g. significantly shorter than a decade.

Powell and Danby's 2nd generation Maglev-2000 system is specifically designed to address these two factors. First, the guideway construction cost is projected to be only about 25 million dollars per mile, a factor of 2 or more lower than 1st generation systems. To achieve this, low cost prefabricated monorails are used for most of the elevated guideway construction. Figure 13 shows an artist's view of a Maglev-2000 passenger vehicle on the monorail guideway.

The prefabricated monorail beams would be mass produced in factories, with their guideway loop panels, sensors, electronic equipment, etc. attached to them at the factory. The beams and piers would then be transported by truck or rail to the construction site, where they would be quickly erected on pre-poured concrete footings or pilings, using conventional cranes. Guideway cost would be kept low by the use of conventional box beams for the monorail, which minimizes the amount of materials required, and prefabrication, which minimizes expensive field construction. Disruptions to traffic and other activities would also be minimized, which would help to reduce local opposition to guideway construction.

Figure 13 Artist's Drawing of Maglev-2000 Vehicle on Monorail Guideway

The 2nd generation Maglev 2000 System incorporates a number of unique new inventions that enable much greater capability than the 1st generation Japanese and German Maglev Systems, and are crucial for the MAPS application. These include:

1. Quadrupole magnets that enable Maglev 2000 vehicles to travel on both monorail and flat surface guideways, with much lower magnetic fringe field strength than the single dipole loops used in the Japanese system.

2. Maglev-2000 vehicles can smoothly transition back and forth between monorail and flat planar guideways at high speeds.

3. Maglev-2000 vehicles can electronically switch from one guideway to another at high speed, without requiring mechanically moving a long switch section. Both the Japanese and German 1st generation Maglev systems require moving long cumbersome sections of guideway in order to switch from one guideway to another. Moving the guideway switch takes a long time, and the vehicle speed must be low.

4. Maglev=2000 vehicles can use existing RR tracks that have been adapted for levitated travel at very low cost.

Figure 14 shows a cross sectional view of the Maglev-2000 superconducting quadrupole. The 2 superconducting loops that form the quadrupole carry oppositely directed currents, with the separation between the loops equal to their width. The 2 loops can operate as separate circuits or be connected together into a single circuit.

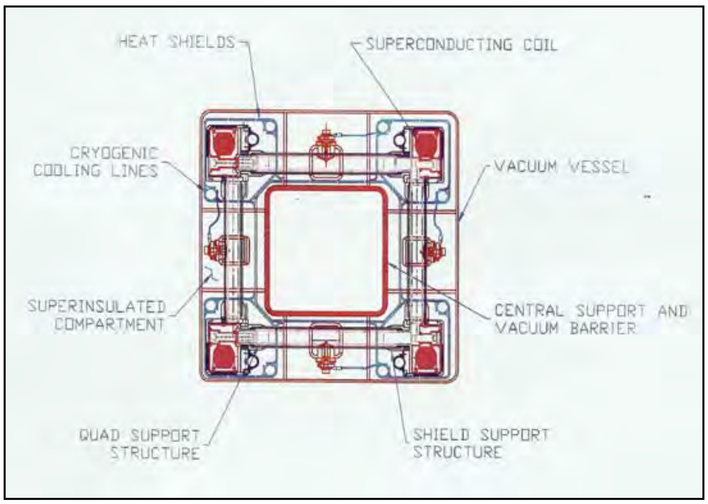


Figure 14 Superconducting Maglev-2000 Quadrupole Magnet Cross Section

The quadrupole has 4 magnetic poles that alternate in sign around its circumference. When used on a monorail guideway, the vertical side of a quadrupole interacts with the aluminum loops attached to the adjacent vertical side of the monorail guideway. When operating on a planar guideway (Figure 4), the bottom face of the quadrupole magnetically interacts with aluminum loops located on the guideway beneath the vehicle.

The ability to operate on a planar guideway as well as monorail also helps to reduce the construction cost of Maglev routes. When operating in densely populated urban and suburban areas,, the Maglev-2000 vehicles does not need to build a new, very expensive guideway with its accompanying disruptions and modifications to existing infrastructure. Instead, Maglev 2000 can transition to, and operate on, existing RR tracks to which aluminum loop guideway panels have been attached on the cross-ties. Conventional trains can continue to use the RR tracks, given appropriate scheduling. The cost of attaching guideway panels to enable levitated maglev-2000 operation is very small, only about 4 million dollars per mile, compared to the high cost of a new elevated guideway for Maglev systems that cannot operate on existing RR tracks.

Turning to the 2nd factor affecting Maglev implementation, revenues and net profits, the Maglev-2000 system is designed to carry trucks as well as passengers vehicles on its dual-use guideway. It accomplishes this because the powerful superconducting Maglev-2000 Quadrupoles can be located along the length of a Maglev vehicle without producing magnetic fields inside the vehicle that significantly exceed the natural Earth ambient value. This is a result of the considerably lower value of magnetic fringe fields from a quadrupole, compared to the dipole configuration used in the 1st generation superconducting Maglev system.

The gross revenues from transporting 3000 trucks daily on a Maglev-2000 route (1/5th of the daily truck traffic on a typical Interstate Highway) are equivalent to 180,000 passengers per day, assuming a revenue of 30 cents a ton mile (typical U.S. outlay) for trucks, and 10 cents a passenger mile. The truck revenues alone would enable a payback time of less than 5 years for the Maglev-2000 guideway cost, an attractive opportunity for private investment.

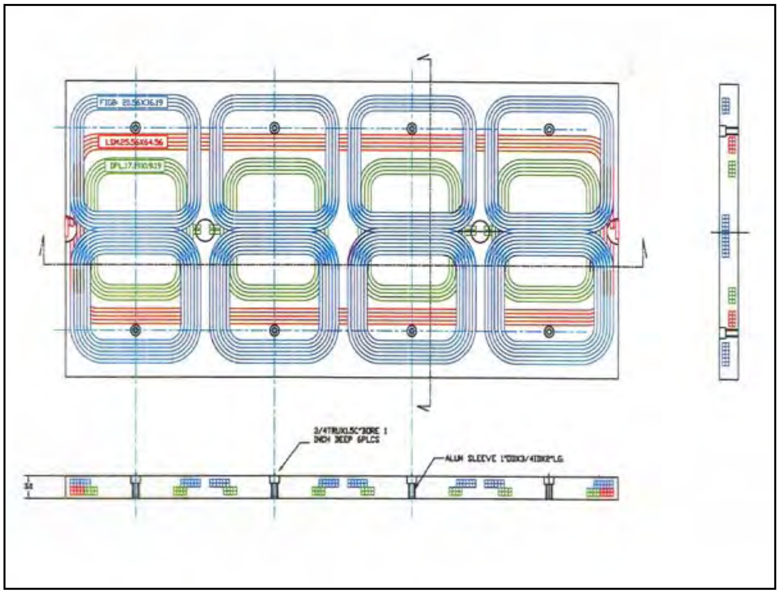
The same Maglev-2000 guideway could also transport personal autos together with their passengers, offering travelers the opportunity to take their personal cars with them on long trips, at a lower cost than by highway. The Maglev-2000 system could also transport and deliver high value freight containers in a much shorter time than by conventional rail.

The ability of M-2000 vehicles to travel on planar guideways also enables high speed electronic switching to off-line stations. This allows Maglev-2000 vehicles to bypass at high speed stations they are not scheduled to stop at, enabling stations to be closely spaced for convenient access, which increases revenue potential for the system, compared to having only a single or few stations in a given metropolitan area.

Figure 15 shows a drawing of the Maglev-2000 aluminum wire loop guideway panels. It has 3 sets of multi-turn aluminum loops: 1) a sequence of 4 short independent Figure of 8 loops; 2) a sequence of 4 short dipole loops; and 3) 1 long dipole loop.

When the panels are mounted on the vertical sides of the monorail guideway beam, the Figure of 8 loops provide levitation and vertical stability. The dipole loop on each side of the beam are connected together into a null flux circuit that maintains the vehicle in a centered position on the beam – when centered no current flows in the aluminum null flux circuit. When an external force (wind, curves, etc) acts to push the vehicles away from its centered position, a magnetic force develops that opposes the external force. The long dipole loop is part of the Linear Synchronous Motor (LSM) propulsion system, in which the loops on a sequence of panels are connected in series to form an energized block along which the Maglev vehicles travels. The energized block is typically on the order of 100 meters in length; as the vehicle leaves an energized block, its AC propulsion current is switched from the block being exited into the next block that the vehicle is entering.

Figure 15. Drawing of aluminum loop guideway panel providing vertical lift and stability, lateral stability, and linear synchronous propulsion.



For the planar guideway, the same panel design is used, with the panel laid flat on the planar surface beneath the line of quadrupoles on the moving vehicle. The Figure of 8 loops now provide lateral stability, generating magnetic restoring forces if an external force acts to displace the vehicle from its centered position on the guideway. The dipole loops act individually, with inductive currents that levitate and vertically stabilize the vehicle as it passes overhead. The LSM loops function in the same way as they do on the monorail guideway.

The planar guideway panel configuration can also be used to levitate and propel Maglev vehicles along existing RR tracks, with the panels attached to the cross-ties of the RR tracks.

The planar guideway is also used for high speed switching. At a switch section, there are two lines of overlapping guideway loops, which can be either electronically open circuited or closed circuited, depending on the desired switching action. Line A of guideway loops runs straight ahead on the main line, while the second line (Line B) of loops diverges laterally at a rate acceptable for passengers. If the loops in line A are close-circuited and those in Line B are open circuited, the vehicle travels straight ahead on the main route. If the reverse is used (Line A open, Line B closed), the vehicles diverges laterally from the main route onto a secondary guideway that leads to the off-line station. The high speed vehicle then decelerates on the secondary guideway that leads to the off-line station. When the vehicle leaves the station to rejoin the main line, it accelerates on an out-bound secondary guideway that leads to the switch section where the high speed vehicle re-enters the main line.

The next section describes the fabrication and testing of full scale Maglev-2000 components discussed above in order to determine their performance and validate the projections of their cost.

Fabrication and Testing of Full-Scale Maglev-2000 Components

Figure 16 shows one of the two wound superconducting loops used for the Maglev-2000 quadrupole. The loop has 600 turns of NbTi superconducting wire, supplied by SuperCon, Inc. of Shrewsbury, MA.(14) At the design current of 1000 Amps in the NbTi wire, the Maglev-2000 quadrupole has a total of 600,000 Amp turns in each of its 2 superconducting (SC) loops. The SC winding is porous, with small gaps between the NbTi wires to allow liquid Helium flow to maintain their temperature at 4.2 K, and to stabilize them against flux jumps and micro movements.

Figure 16 NbTi Superconductor Loop for Maglev-2000 Quadrupole

Figure 17 NbTI Superconducting Loop Enclosed in Stainless Steel Jacket

Figure 17 shows the SC loop enclosed in its stainless steel jacket. Liquid Helium flows into the jacket at one end and exits at the end diagonally across from the entrance providing continuous Helium flow through the SC winding. Before insertion of the SC loop into the jacket, it is wrapped with a thin sheet of high purity, aluminum (5000 residual resistance ratio) to shield the NbTi superconductor from external magnetic field fluctuations. After closing the jacket, a second layer of high purity aluminum is wrapped around it for additional shielding.

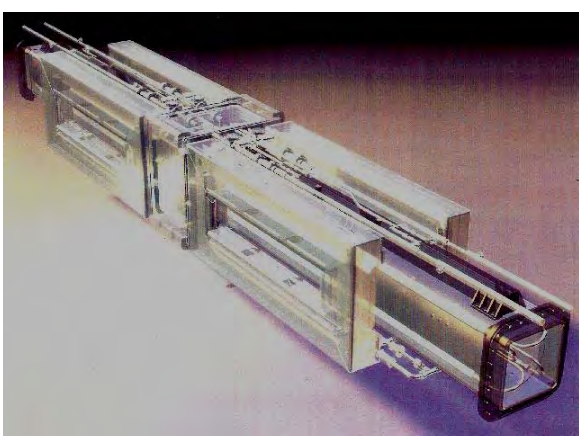


Figure 18 CAD-CAM Drawing of Maglev-2000 Superconducting Quadrupole Magnet Assembly

Figure 18 shows a CAD-CAM drawing of the complete Maglev-2000 cryostat that holds 2 superconducting quadrupoles. The magnetic polarity of the front SC quadrupole is opposite to that of the rear quadrupole. This allows levitation at lower speed than if the 2 quadrupoles had the same polarity, due to less L/R decay of the currents induced in the aluminum guideway loops. The 2 SC loops are supported by a graphite-epoxy composite structure that resists the magnetic forces – due both to the forces in a loop from its self-current, and to the forces between the 2 loops – that act on them.

Figure 19 shows the SC loops, support structure, and cooling currents for the Maglev-2000 quadrupole being assembled in Maglev-2000's facility on Long Island. The SC loops have a 10 K thermal shield, which is cooled by Helium exiting from the jacket holding the SC loop. The SC quadrupole structure is then enclosed by an outer layer of multi-layer insulation (MLI) consisting of multiple alternating layers of glass fiber and aluminum foil. A second thermal shield encloses the SC quad, and maintained at ~70 K by the helium out-flow from the 10 K primary thermal shield.

Figure 19 Assembly of Maglev-2000 Superconducting Quadrupole

Figure 20 shows the completed SC quadruple enclosed in its vacuum cryostat. The assembly was tested with the quadrupole magnetic levitation and propulsion forces using DC current in the aluminum loop guideway assembly beneath the quadrupole as a stand-in for the induced currents. The quadrupole was successfully tested to its full design current of 600,000 Amp turns. The magnetic forces between the quadrupole and the guideway loop assembly were measured as a function of vertical separation and lateral displacement from the centered position, and longitudinal position in the direction of movement along the guideway. The measured forces agreed with 3 D computer analyses.

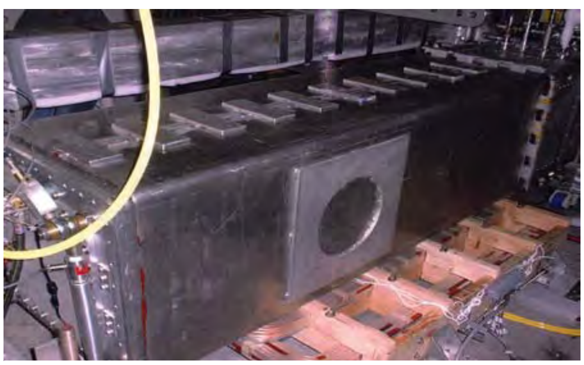


Figure 20 Completed Maglev-2000 Quadrupole Enclosed in Cryostat

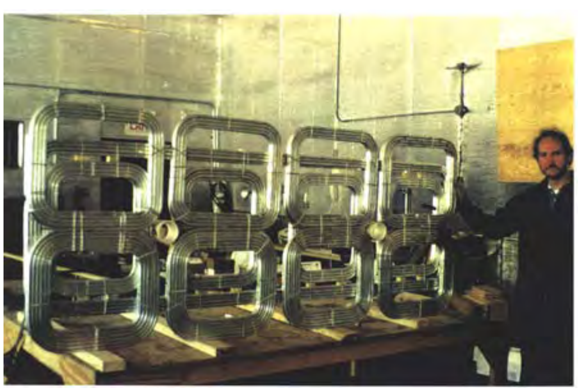


Figure 21 Completed Guideway Panel with Figure of 8 Dipole and LSM Propulsion Loops

In the time following the Maglev-2000 quadrupole tests, high temperature superconductors have become much more capable, and are being commercially produced in substantial amounts. Using YBCO high temperature superconductor wire, it appears very possible to fabricate Maglev-2000 quadrupoles that would be much simpler in construction, with much easier refrigeration requirements. The YBCO superconductor would operate at 65K with pumped liquid nitrogen coolant and a much simpler on-board cryocooler than would be required if NbTI superconductor at 4.2K were used. One Maglev-2000 quadrupole requires 3600 Amp turns of superconductor. At 10 dollars per Kilo Amp meter, which appears achievable with large scale production of high temperature superconductor, the superconductor for it would cost $36,000. A passenger vehicle with 8 quadrupoles would then have a superconductor cost of $288,000, while a truck carrying vehicle with 16 quadrupoles would then have a superconductor cost of $576,000. Future Maglev-2000 quadrupoles will probably involve high temperature superconductors with liquid nitrogen coolant, rather than NbTI superconductor with liquid Helium coolant.

The guideway loop panels (Figure 21) contain 3 sets of wound aluminum loops, composed of a set of 4 Figure of 8 loops, a set of 4 dipole loops, and 1 long LSM propulsion loop. The aluminum conductor has a ~10 mil layer of nylon using a dip process to coat the conductor. The nylon insulation withstood 10 Kilovolt tests without breakdown. Figure 21 shows a completed guideway loop panel with all of its 9 loops.

The completed panel is then enclosed in a polymer-concrete structure for handling and weather protection. Polymer concrete – a mixture of aggregate, cement and plastic monomer – can be cast into virtually any form as a slurry. When the monomer polymerizes (the rate of polymerization is controlled by the amount of added promoter), the resulting concrete-like structure is much stronger – a factor of 4 or greater – than ordinary concrete and not affected by freeze-thaw cycles, salt, etc. Figure 22 shows a completed section of a polymer concrete panel left outside of the Long Island facility for 2 years. It was subjected to a wide range of weather conditions and multiple freeze-thaw cycles over the 2 year period, without any degradation.

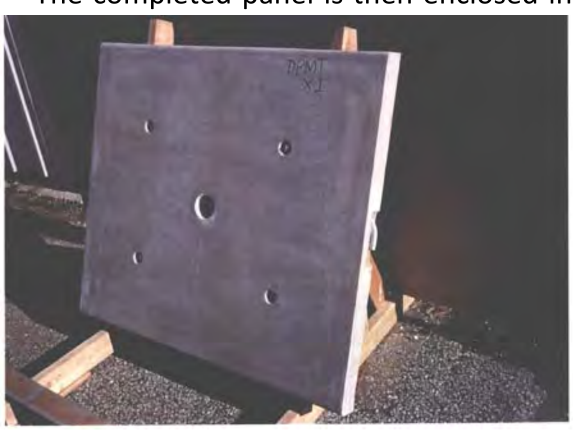


Figure 22 Polymer Concrete Panel with Enclosed Aluminum Loop

After being fabricated at the Maglev factory, the guideway panels would be attached to the sides of the monorail or the surface of planar guideway beams to be shipped to a construction side for an elevated guideway, or transported to existing RR trackage that was to be modified for use by Maglev-2000 vehicles.

The monorail guideway beam is a hollow box beam made with reinforced concrete. Beam length is 22 meters and weight is 34,000 kg. It uses post tension construction, which allows the tensioning cables in the base of the beam to be re-tightened if some stretching were to occur. The beam is tensioned to have a 0.5 cm upwards camber at the midpoint of the beam when it is not carrying a Maglev vehicle. When the Maglev vehicle is on the beam, the beam flattens out to a straight line condition, with no vertical dip or camber along its length.

Figure 23 shows a photo of the fabricated beam after transport by highway truck from the manufacturing site in New Jersey to Maglev-2000's facility in Florida. No problems in transport by highway were encountered.

Figure 23 Photo of 72 Foot Long Monorail Guideway Beam Delivered to Maglev-2000 Facility in Florida From Construction Site in New Jersey

Fabrication and testing of the basic Maglev-2000 components – superconducting quadrupole magnets, aluminum loop guideway panels, monorail guideway beam, and vehicle body – have been successfully carried out. The next step for the development of the commercial 2nd generation Maglev-2000 system is to test operating vehicles on a guideway.

The MAPS system uses the same components – Superconducting quadrupoles, monorail guideway beam (on-grade, rather than elevated, however), aluminum guideway loop panels for vertical lift, horizontal & vertical stability, and magnetic propulsion, and a planar surface electronic switch between the main guideway and sidings.

The principal difference between the Maglev-2000 transport guideway and the MAPS guideway (Figure 6) is the addition of iron plates in the guideway panels. The iron plates provide a substantial fraction of the lift force, without having to induce currents in the aluminum guideway loops. This reduces I^2R losses in the aluminum loops, increasing propulsion efficiency. The MAPS suspension is still inherently stable, because the stability forces from the null flux aluminum loop circuits are greater than the destabilizing forces associated with the iron plates, as analyzed and described in reference (17).

The MAPS vehicles are much simpler and cheaper than these used by the Maglev-2000 System to transport passengers, autos, highway trucks, and freight containers. They are simple sled type structures with attached superconducting magnets and a compact cryogenic refrigeration unit and its associated plumbing. The powered roller bars on the upper surface of the sled are similar to units that operate in many industrial facilities.

Overall, MAPS would use virtually the same technology as Maglev-2000's transport system except that it would be simpler and lower in cost.

5. US and World Markets for Maglev Energy Storage

The market for MAPS energy storage systems is very large, both in the US and abroad. Table 5 shows the annual total electric generation for the US and the World. US annual generation in 2008 is approximately 20 percent of the World total. By 2035 AD total World electric generation will almost double from 2008 values as Asian nations rapidly industrialize. (17)

Replacing expensive electricity from natural gas peaking plants with much less expensive power from baseload plants that used MAPS would be a very large market. In the US, storing 883 million MWH at an average cost of 3 cents/KWH would bring in 28 Billion dollars annually, sufficient to cover all the costs and pay back the capital cost of the MAPS facilities over a 30 year period.

Assuming that the cost of peaking power from natural gas plants was 9 cents/KWH greater than the cost of baseload power, that would then correspond to a production power savings of 6 cents per KWH using MAPS (+9-3 = 6 cents saved), a net savings of 56 Billion dollars annually. If the cost differential of peaking power from natural gas, compared to baseload power, was greater than 9 cents/KWH, the net savings using MAPS would be even greater than 56 Billion dollars per year.

Table 5

MAPS Market in US and World

	US (Million MWH)	World (Million MWH)	
Parameter	2008	2008	2035 (EIA Projection)
Total Electric Generation	4,157	18,800	35,200
Coal	1,996	8,000	15,000
Natural Gas	883	4,000	7,500
Nuclear	806	2,600	3,600
Hydro	255	3,000	5,400
Wind	55	340	1,500
Solar	0.9	5	180
Potential Market for MAPS (Natural Gas+Wind+Solar)	939	4300	9200
Annual MAPS Revenue w/o Profit @ 3Cents/KWH (Natural Gas Power Replaced)	$28 Billion	$130 Billion	$280 Billion
Annual MAPS Revenue w/o Profit @3 Cents/KWH (Coal & Natural Gas Replaced with Wind & Solar)	$88 Billion	$370 Billion	$730 Billion

To replace all US power generated from coal and natural gas power plants, which account for virtually all of US power generated using fossil fuels, would cost 88 Billion dollars, based on 3 cents per KWH. The corresponding cost of CO2 emissions that were eliminated would be about 40 dollars per ton – a reasonable price to pay. The elimination of coal and natural gas plants would be replaced with nuclear, wind, and solar plants.

The corresponding total 2008 World market for MAPS would be about 5 times greater than in the US, since the total World generation is approximately 5 times greater than the US market. The 2008 MAPS revenue for eliminating World natural gas power generation would be 130 Billion dollars per year; for eliminating coal and natural gas, the revenues would be 370 Billion dollars per year.

The EIA (Energy Information Administration) projects that World electrical generation will double by 2035 as World population increases and countries become more industrialized. Coal and natural gas power plants will continue to dominate electric production, accounting for almost 70% of total power production.

It is disheartening that wind and solar power play such a minor role in EIA projections for 2035, only about 5% of the total. To achieve the goal of major reduction in World CO2 emissions, wind and solar will have to play a much greater role. They can do so, using MAPS storage to enable wind and solar to reliably deliver large amounts of power on demand.

The annual revenues shown for MAP:S are very large, and correspond to a major World industry with many economic and environmental benefits.

6. Proposed Demonstration Program for Maglev

The proposed SUMMIT (SUperconducting Maglev Multi Integrated Testing) facility will demonstrate the technical and economic feasibility of Maglev energy storage application [a]. In addition, it will also demonstrate the technical and economic feasibility of 2 other Maglev applications: [b) and c)]

a) Efficient, low cost storage of electrical energy generated by clean, non-polluting renewable energy sources.

b) Reducing the cost and energy required for long-distance truck transport, together with reduction of the pollution and highway damage that they cause.

c) Low cost, energy efficient long-distance transport of large amounts of fresh water to regions with insufficient water resources, especially the U.S. Southwest.

The three areas are particularly relevant to the Nevada location of the facility.

Wind and Solar renewable energy resources hold great promise in supplying large amounts of clean energy without the greenhouse gas emissions that are contributing to global warming. Nevada is a very attractive location for large amounts of wind and solar power.

However, wind power is highly variable, and only blows about 30% of the time, frequently blowing when electrical demand is low, and frequently not blowing when demand is high. Solar power is more regular, but at its output is low during peak demand periods in the morning and in the late afternoon. If wind and solar power are to become a major source of energy for the U.S., a low cost, efficient way to store large amounts of electrical output from them must be developed, so that the energy can be delivered to the electrical grid when needed.

The I 15 highway corridor is heavily congested, with long distance trucks being a major contributor to the congestion. They emit large quantities of pollution, especially diesel particulates that are very harmful to peoples' health. The highway trucks cause extensive damage to highways, shortening their life, and increasing maintenance and repair costs. A single 18-wheeler highway truck causes as much damage as thousands of autos, according to estimates from transportation experts.

Finally, Nevada and the Southwest in general are very short of water. Less water flows down the Colorado River, Lake Mead is drying up, and underground water table levels are rapidly dropping. There is lots of fresh water in the Columbia River, but pipeline delivery would be far too expensive for Nevada, Southern California, Arizona, and New Mexico.

The 2nd generation Maglev-2000 System can transport very large tonnages at high speed and low cost, with very high energy efficiency. It can transport heavy highway trucks at hundred of mph at considerably lower cost than driving by highway. A trucking company using Maglev would only need 1/5th as many trucks, compared to going by highway.

Similarly, very large quantities of fresh water, hundreds of millions of gallons of water per day, can be delivered over distances of hundreds of miles using Maglev at very low cost – less than 1 dollar per 1000 gallons. Las Vegas could be supplied with water from the Columbia River; Southern California could also get water for its crops from the Columbia River.

As described earlier, MAPS (Maglev Power System) stores electrical energy from wind and solar sources by moving heavy concrete blocks (~100 Tons per block) uphill to a storage site. When the electrical grid needs energy, the concrete blocks are moved downhill by the Maglev vehicles, converting the stored gravitational potential energy back into electrical energy. Going uphill, the Maglev propulsion System acts in the motor mode; going downhill, the Maglev propulsion system acts in the generator mode.

The MAPS storage system is very low in cost, about 2 to 3 cents per kilowatt hour stored, and 95% efficient (output electrical energy/input electrical energy). The storage cost of 2 to 3 cents/kwh is a small fraction of the selling price for peaking power, which can be as much as 50 cents or more per kwh. The only alternative power storage to MAPS is pumped hydro. Batteries, fuel cells/electrolyzers, flywheels, etc are too expensive and inefficient. Pumped hydro has many problems – there are very few sites where it can be implemented, the environmental effects are very objectionable, and the overall energy efficiency is low. Only 70% of the input energy to pumped hydro is returned as electricity to the grid.

The 3 types of Maglev vehicles that would use the common type of guideway are shown in Figure 24, 25, and 26. The water transport vehicle has an inflatable bladder (Figure 25). When transporting water from a source to users, the bladder is inflated with water. After finishing the delivery, the bladder is completely deflated as the vehicle returns for the next load of water. This reduces air drag and propulsion energy for the return trip.

The highway truck transport Maglev vehicle (Figure 26) has a streamlined shell that encloses the trucks carried inside the vehicle, again to minimize air drag and propulsion energy. The trucks simply drive onto the Maglev vehicle through an entrance at an end of the vehicle. After the trucks are onboard the entrance closes, and the Maglev vehicle begins its trip to the desired destination. Upon reaching the destination, the other end of the vehicle opens and the trucks quickly drive off. They then travel by highway for a few miles to deliver their loads. The procedure is similar to that used for the trucks that travel on railroad cars through the English Chunnel. Drive on-Drive off time for the Chunnel trucks is only 90 seconds. During transport, the trucks are anchored to the floor of the Maglev vehicles by movable supports.

The water delivery and truck transport vehicles typically will travel for hundreds of miles between origin and destination at high speeds, i.e. 200 mph or more, so that minimizing air drag and propulsion energy is important.

For energy storage, however, typical trip distances between the lower altitude and higher altitude stations is only a few miles at most, and Maglev vehicle speeds are substantially lower, on the order of 100 mph, than those for long distance transport of highway trucks and water. Accordingly, the vehicles do not have to be streamlined. Instead, as illustrated in Figure 24, the Maglev energy storage vehicles have a simple flat surface on which the concrete blocks sit. The surface has roller bars and tilts to unload and load the blocks at the storage yards. For example, when a Maglev vehicle transporting a concrete block uphill reaches the storage yard, its surface tilts, causing the block to move sideways onto an adjoining surface at the storage yard. To load a block onto the vehicles the roller bars on the storage surface tilt slightly, causing the block to move back onto the vehicle. The transfer process is fast and automatic, taking less than 1 minute. Alternatively, the roller bars on the surface of the vehicles could be powered to unload and load blocks when desired, with no need to lift the surface of the Maglev vehicles. Transporting a 100 ton block 3000 feet uphill stores 250 kilowatt hours of electric energy. As an example, transporting 200 blocks per hour uphill could store 50 megawatt hours of electric energy. Over an 8 hour period when the solar farms was at peak output, this would enable the storage of 400 megawatt hours of electric energy, ready to be delivered at whatever rate the electric grid would request. The rate would be controlled by the number of Maglev vehicles in a multi-vehicle consist, and their speed on the guideway. Power storage demand rates could be as low as a few megawatts to hundreds of megawatts, depending on source output and grid demand.

Table 6 summarizes the principal features and parameters of the 3 Maglev applications. All 3 applications would use the common guideway design and on-grade construction, with the difference being that the energy storage guideway would go uphill at a relatively steep angle, e.g. 30 degrees, while the water and truck transport guideway would primarily follow relatively flat terrain, only climbing hills when necessary.

All 3 Maglev applications have lower costs per unit of transport or energy storage than present technologies do and higher energy efficiencies. For example, the unit cost of Maglev energy storage is about 2 to 3 cents per KwH(e) compared to about 10 cents per KwH(e) for pumped hydro. The efficiency of Maglev energy storage is approximately 95% -- that is, 95% of the input electrical energy is returned to the electrical grid, while the efficiency of pumped hydro is only about 70%.

With regard to fresh water transport, the situation is essentially the same. The unit cost for transport is much less for Superconducting Maglev than by pipeline, approximately \$1 per 1000 gallons for a delivery distance of 300 miles, compared to about \$5 per 1000 gallons for pipeline. The Man Made River pipeline in Libya delivers approximately 1 Billion gallons of water per day to Libya's coastal cities from inland wells, over a distance of about 300 miles. The construction cost of the Man Made River was 30 Billion dollars, built many years ago, when construction costs were much lower. At amortization and maintenance charges of 5% per year, which is low, this amounts to approximately $5 per 1000 gallons, not including the cost of pumping energy, which is considerably greater than the energy cost of water transport by Superconducting Maglev.

Even more important, its pipelines are not practical in terrain that is substantially rising and falling in elevation, but requires installation in relatively flat terrain. A 300 foot rise or fall in elevation will decrease or increase the water pressure inside the pipeline by 150 psi, an unacceptable amount for a pipeline diameter of 13 feet or greater, which is needed to carry a billion gallons daily. If the pipeline route goes uphill by a substantial amount, a pump will be required to compensate for the rise in elevation. Likewise, if it goes downhill by a substantial amount, a turbine will be needed to lower the pressure in the pipe. The output power from the turbine can be fed to the pump but there will be substantial hydraulic and electrical losses, that make it impractical for large pipelines in terrain with substantial changes in elevation, such as the route between the Columbia River in Oregon and Las Vegas and the rest of the U.S. Southwest.

In contrast, elevation changes pose no problem for superconducting maglev transport of water. The high speed train of Superconducting Maglev water transport vehicles simply coasts up and down hill with small changes in velocity – increasing speed slightly going downhill, and decreasing speed slightly going uphill. No propulsion energy input is needed; in fact, once the Superconducting Maglev water train gets up to its operating speed, it can coast for hundreds of miles before requiring more propulsion power.

The third application is the transport of highway trucks. Not only can Maglev transport highway trucks 5 times faster than if they went by highway (300 mph vs 60 mph) but this allows trucking to operate with far fewer trucks in their fleet to make deliveries, saving a great deal of money. Moreover, the operating cost per ton-mile by Maglev is only about 10 cents per ton mile compared to approximately 30 cents per ton-mile by highway, and the energy efficiency for truck transport by Maglev is considerably greater than by highway.

The cost figures for Maglev include the costs for amortization of the guideway and vehicles, propulsion energy, maintenance, and system personnel. In contrast, the costs for truck transport by highway do not cover the repair and maintenance costs to the highway caused by heavy trucks – one truck can cause as much highway damage as several thousand cars, according to the U.S. DOT, and do not include the costs of the deaths and injuries due to truck accidents not the congestion delay costs.

The SUMMIT (SUperconducting Maglev Multi Integrated Testing) facility will demonstrate and certify Maglev vehicles for the 3 following types of service:

1. Electrical energy storage

2. Long distance transport of fresh water
3. Long distance high speed transport of highway trucks.

The 3 types of Maglev vehicles will use a common design on-grade guideway that can be installed at low cost. The guideway beam will be poured concrete monorail box beam positioned on a standard type concrete highway paved lane that will be approximately 20 feet wide.

The on-grade guideway beam has aluminum loop panels on each side of the beam. The aluminum loops interact with superconducting magnets on the vehicle to levitate and propel the Maglev vehicles. The levitation process is inherently stable; any external force acting on the Maglev vehicle – winds, curves, grade, etc., is instantly opposed by magnetic forces that act to keep the vehicle levitated. A set of aluminum loops in the panel carry AC current that push on the vehicle’s superconducting magnets propelling it along the guideway.

The SUMMIT Facility would test full scale prototypes of the 3 Maglev vehicles on the on-grade guideway, the SUMMIT facility would have 2 phases, as described below:

<u>Phase 1: Design, Construction of Guideway and Vehicles, and Initial Testing</u>

The Phase 1 guideway would be approximately 4 miles in length (Figure 27). One end of the guideway would go uphill at an angle of 20 to 30 degrees, with an elevation rise in the range of 1500 to 3000 feet, depending on the location of the facility. The length of the ascending portion of the guideway would be in the range of 1/2 to 1 mile, again depending on the location of the facility, the remaining ~3 to 4 miles of the guideway would be on relatively flat terrain.

The following tests would be carried out on the 3 types of Maglev vehicles:

- Stable levitation of the vehicles when moving along the guideway.
- Stable levitation when stopped at designated locations.
- Acceleration to design speed using the magnetic propulsion system in the motor mode.
- Deceleration to a stop at a designated location using the magnetic propulsion system in the generation mode.
- Measurement of magnetic restoring forces as a function of displacement from the equilibrium suspension point.
- Measurement of propulsion energy efficiency, air drag losses, and I^2R losses in the aluminum guideway loops.
- Measurement of the amount of vehicle kinetic energy that can be recovered during braking and returned to the electric grid.

- Braking and vehicles set-down response if propulsion power input to the guideway is suddenly shut-off.
- Ability to load and unload 100-Ton Block from Maglev vehicle and to transport up and down grade.
- Ability to load and unload 50,000 gallons of water from Maglev vehicle and transport it along guideway.
- Ability to load and unload 2 fully loaded highway trucks on a Maglev vehicle and transport it along guideway.

At the end of Phase 1, which will be carried out over a period of 3 years, the following will have been established:

- Feasibility of Maglev for energy storage, water transport and highway truck transport.
- Performance data on load, speed, and power capability of Maglev transport vehicles.
- Safety data on vehicle stability and operating margins
- Optimum manufacturing methods for vehicles, guideway beams and panels, superconducting magnets, controls, etc., together with data on manufacturing costs.

Phase 2: Extended Testing of Vehicles and Guideway System Developed in Phase 1

Phase 2 would extend the guideway constructed in Phase 1 and configure it for continuous running. The ~4 mile guideway built in Phase 1 would be a single line, requiring stopping at each end, and then accelerating back to speed on the return leg. While this configuration can demonstrate speed, acceleration, deceleration, load capability, response to external forces during the time it takes to travel from one end of the guideway to the other, it cannot demonstrate long term reliability and running performance.

Phase 2 will extend the guideway to a length of ~20 miles with a loop at each end (Figure 28), so that the Maglev vehicles can run at high speed continuously along the guideway. Operating at 6000 hours per year and 200 mph, a Maglev vehicle will accumulate a total running distance of 1.2 million miles per year, demonstrating high reliability and the ability to operate with very low maintenance. Multiple vehicles will be able to operate on the guideway, e.g., several water transport vehicles coupled together as a single consist, and several highway truck carriers operating as individual vehicles. The energy storage guideway would probably operate as a separate unit to demonstrate better the energy storage and energy retrieval capabilities of Maglev.

The guideway would incorporate electronic switching sections to demonstrate the ability of vehicles to switch from the main line to off-line stations for unloading and loading operations. This main guideway would also incorporate elevated monorail guideway sections enabling vehicles to pass over depressions in the terrain, roadways, etc. Using electronic switching, the Maglev vehicles could also transition to a section of conventional railroad track that had been adapted for Maglev travel.

Phase 2 would be carried out over a period of 2 years. At the conclusion of Phase 2, the following will have been established:

- Reliability of long-term operating performance
- Long term maintenance procedures
- Ability to operate in all weather conditions
- Validation of projected operating costs

After completing Phase 2, the 3 Maglev systems will be ready for commercial implementation.

The projected cost for the 3 year Phase 1 program is 160 million dollars, including design and construction of the 4 mile guideway, prototype Maglev vehicles for the 3 applications, power systems for vehicles propulsion, operating tests of the prototype vehicles, and design of the guideway and vehicles for Phase 2 testing, and initiation of construction for Phase 2.

The projected cost for the 2 year Phase 2 program is 170 million dollars, including the completion of the 20 mile guideway and commercially ready Maglev vehicles for long term testing and the operating tests themselves.

The SUMMIT program will establish the operational feasibility and economic attractiveness of Maglev for the 3 commercial applications:

- Energy Storage
- Long distance transport of fresh water at low cost
- Long distance transport of highway trucks at low cost

The 3 applications will be of benefit to the U.S. generally, but of special benefit to Nevada and the other States of the Southwestern U.S. Nevada and the Southwest in general are prime locations for renewable wind and solar power generation. However, the utility of large wind and solar power farms to meet U.S. power needs as presently constrained by the need to match their time varying output to the demands of the electrical grid. Maglev energy storage will enable very efficient, very low cost storage of electrical power, so that wind and solar power output can meet the time varying power demands of the electrical grid.

The long distance transport of fresh water at affordable cost is critically important to Nevada and its neighboring States in the Southwest. Lake Mead is drying up, water resources are shrinking, and drought conditions are worsening. Bringing large amounts of fresh water from the Columbia River and other sources would ease restrictions on water use for crops and people living in the water scarce areas.

The long distance transport of high trucks by Maglev would greatly ease highway congestion in all parts of the U.S. The I-15, I-5 and other highways in Nevada, California, and their neighboring States are high congested, with long delays. The delays, besides being very aggravating, consume copious amounts of fuel, adding to the Nation’s oil import needs and greenhouse gas emissions. Taking trucks off the highways will reduce accidental deaths and injuries, and also reduce damage to public health from the pollutants and microparticles emitted from the diesel trucks. In addition, damage to highway pavements and the resultant costs of repair and maintenance will be greatly reduced. A single 18 wheeler truck causes as much damage to highways as thousands of automobiles, according to the U.S. DOT.

The cost of developing the 3 Maglev applications will be tiny compared to the social and economic benefits they will produce. The benefits will pay back the cost of development manifold.

Table 6

Principal Features and Parameters of Maglev Technology for Energy Storage, Transport of Fresh Water, and Transport of Highway Trucks as Compared to Present Technologies

Features and Parameters	Energy Storage	Transport of Fresh Water	Transport of Highway Trucks
Configuration of Load Structure on Maglev Chassis	Flat Surface Holding Heavy Concrete Block	Streamlined Expandable Water Bladder	Streamlined Enclosure with Trucks Inside
Transport Load Per Vehicle	100 Ton Block	200 Tons of Water (50,000 gallons)	80 Tons (2 Trucks)
Vehicle Length/Width	24/12 Feet	100/12 Feet	120/12 Feet
Illustrative Performance on a Maglev Route (Can Be Greater)	400 Megawatt Hours 100 Megawatts Storage/Delivery Rate	1 Billion Gallons/Day	6,000 Trucks Daily
Maximum Speed, MPH	150	200	250
Typical Travel Distance, Miles	3 to 5 (Round Trip)	200 to 600 (Round Trip)	200 to 2,500 (One Way)
Present Technology	Pumped Hydro	Pipeline	Driving By Highway
Maglev Energy Efficiency	~95% (Percent of Input Energy	~10 KwH(e) per 1000 gallons (600 mile round trip)	0.16 KwH(e) per Ton Mile
Energy Efficiency w/Present Technology	~60% (Return to Grid)	~20 KwH(e) per 1000 gallons (300 mile one-way)	0.33 KwH(th) per ton mile
Maglev Transport Unit Cost	~2 Cents/KwH(e)	~$1/1000 gallons for 300 mile delivery	~10 cents/ton mile
Present Technology Unit Cost	~10 Cents/KwH(e)	~$5/1000 gallons for 300 mile delivery	~30 cents/ton mile

Figure 24

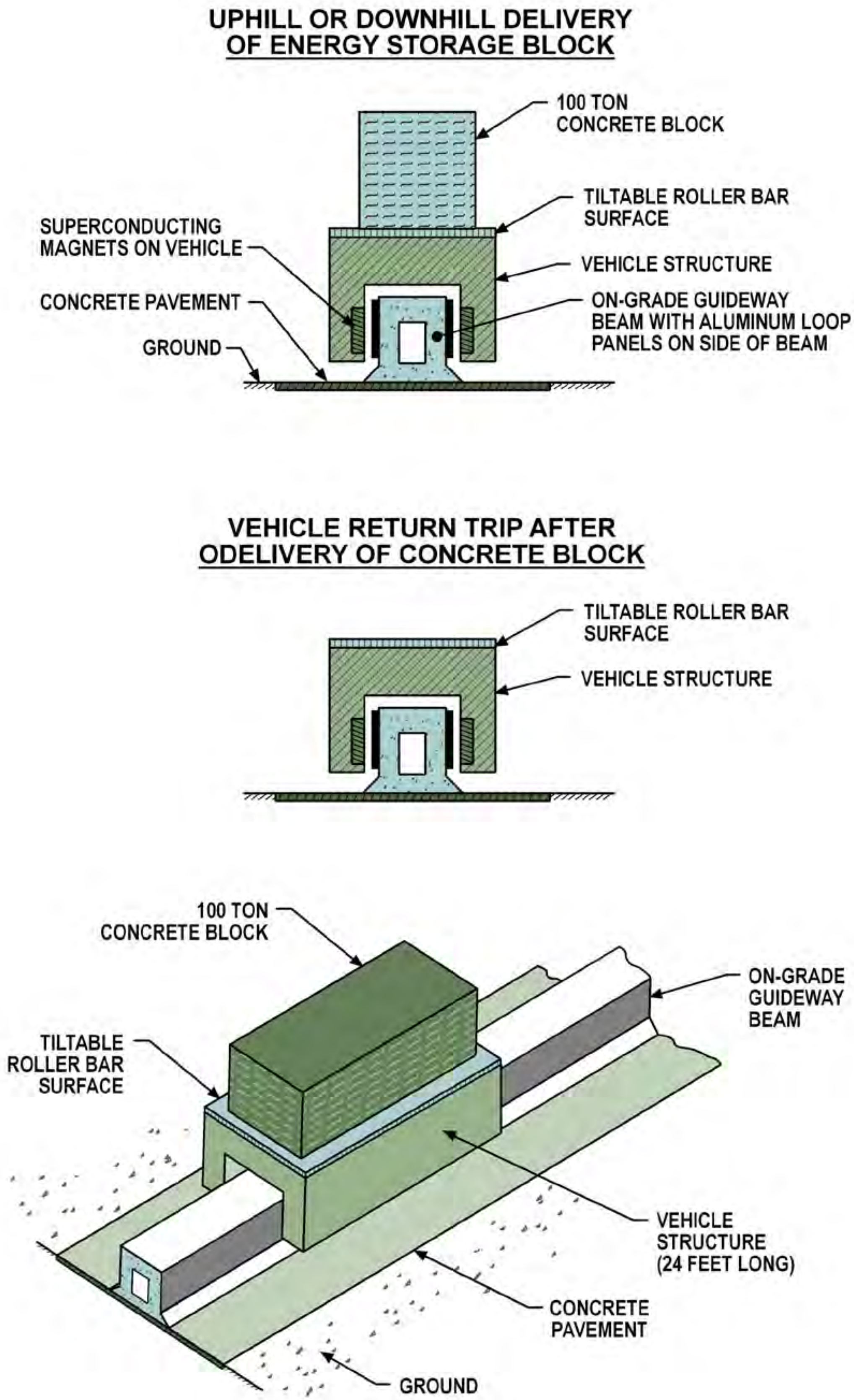

UPHILL OR DOWNHILL DELIVERY
OF ENERGY STORAGE BLOCK
100 TON
CONCRETE BLOCK
TILTABLE ROLLER BAR
SURFACE
SUPERCONDUCTING
MAGNETS ON VEHICLE
VEHICLE STRUCTURE
CONCRETE PAVEMENT
ON-GRADE GUIDEWAY
BEAM WITH ALUMINUM LOOP
PANELS ON SIDE OF BEAM
GROUND
VEHICLE RETURN TRIP AFTER
ODELIVERY OF CONCRETE BLOCK
TILTABLE ROLLER BAR
SURFACE
VEHICLE STRUCTURE
100 TON
CONCRETE BLOCK
ON-GRADE
GUIDEWAY
BEAM
TILTABLE
ROLLER BAR
SURFACE
VEHICLE
STRUCTURE
(24 FEET LONG)
CONCRETE
PAVEMENT
GROUND

Figure 25

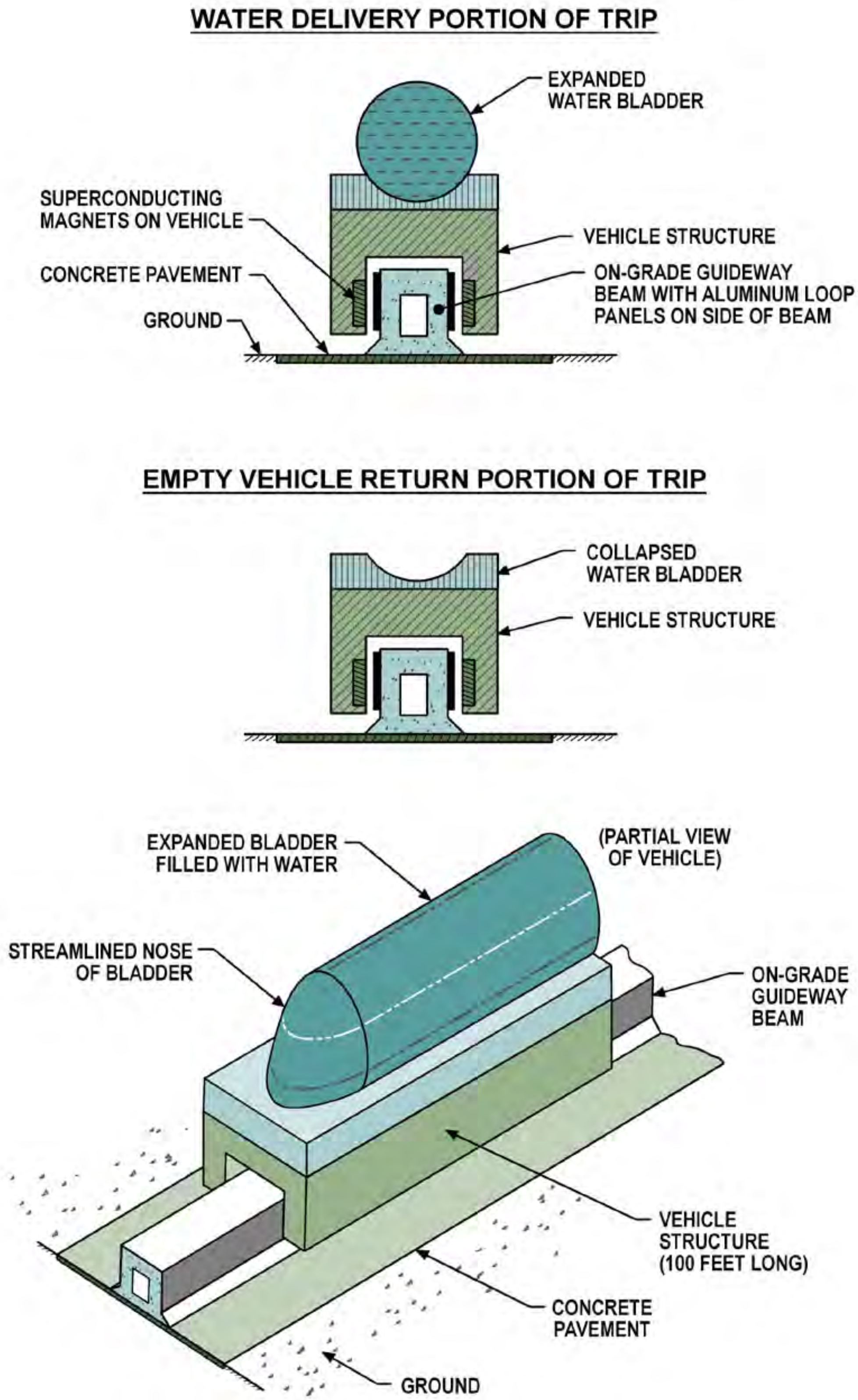
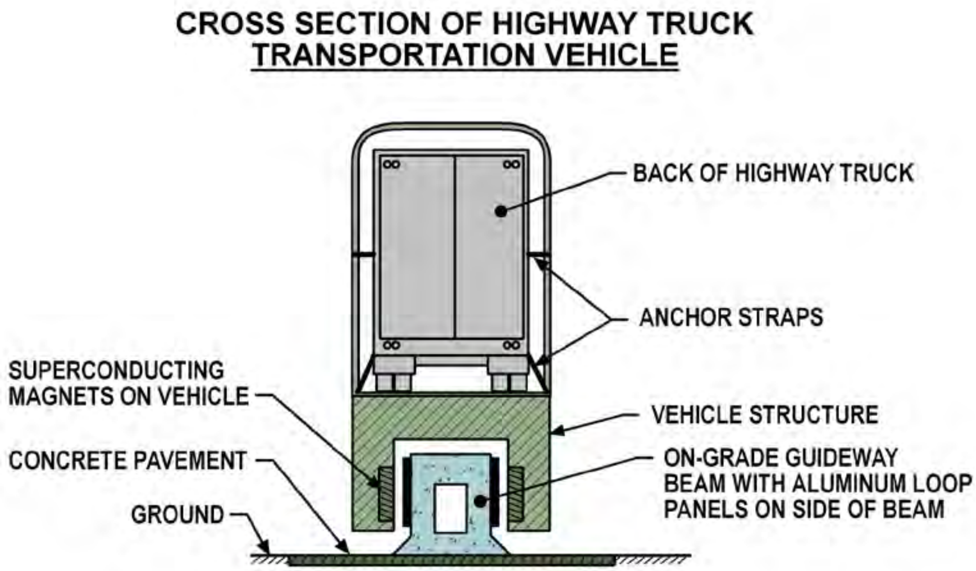

WATER DELIVERY PORTION OF TRIP
EXPANDED WATER BLADDER
SUPERCONDUCTING MAGNETS ON VEHICLE
VEHICLE STRUCTURE
CONCRETE PAVEMENT
ON-GRADE GUIDEWAY BEAM WITH ALUMINUM LOOP PANELS ON SIDE OF BEAM
GROUND
EMPTY VEHICLE RETURN PORTION OF TRIP
COLLAPSED WATER BLADDER
VEHICLE STRUCTURE
EXPANDED BLADDER FILLED WITH WATER
(PARTIAL VIEW OF VEHICLE)
STREAMLINED NOSE OF BLADDER
ON-GRADE GUIDEWAY BEAM
VEHICLE STRUCTURE (100 FEET LONG)
CONCRETE PAVEMENT
GROUND

Figure 26



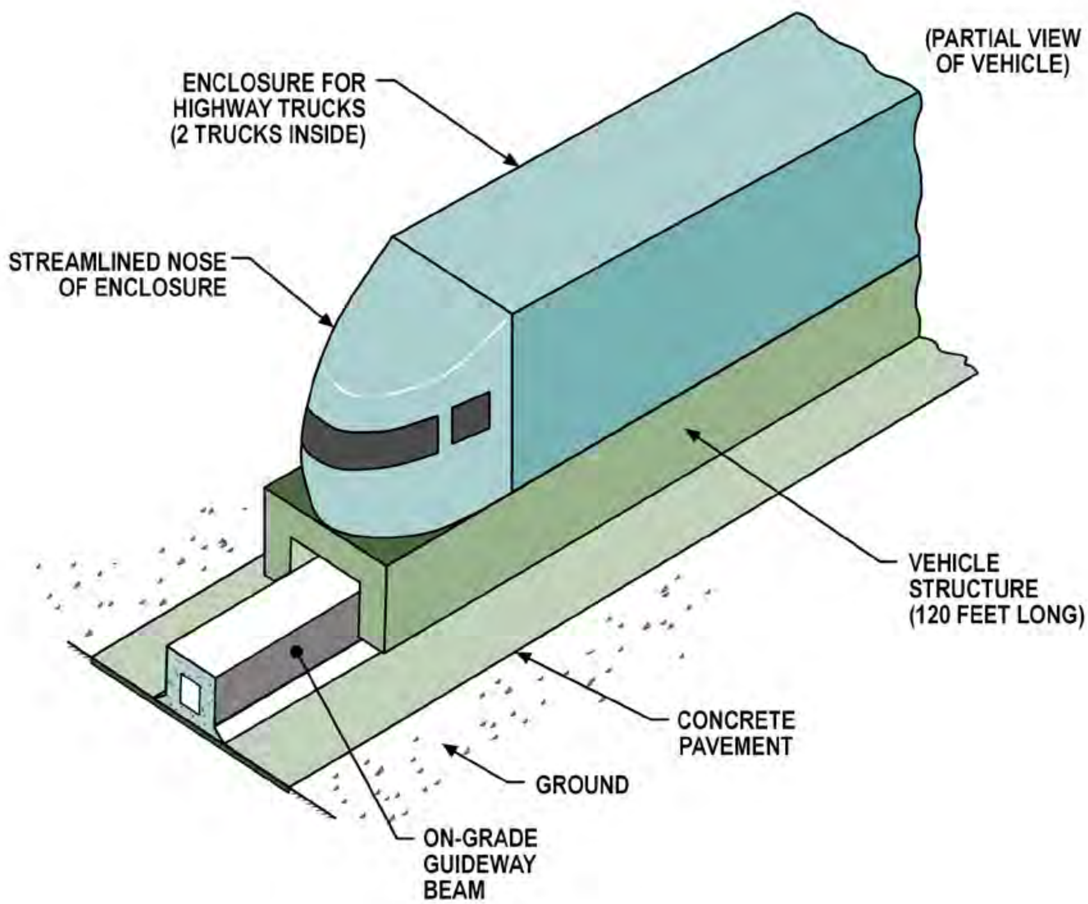
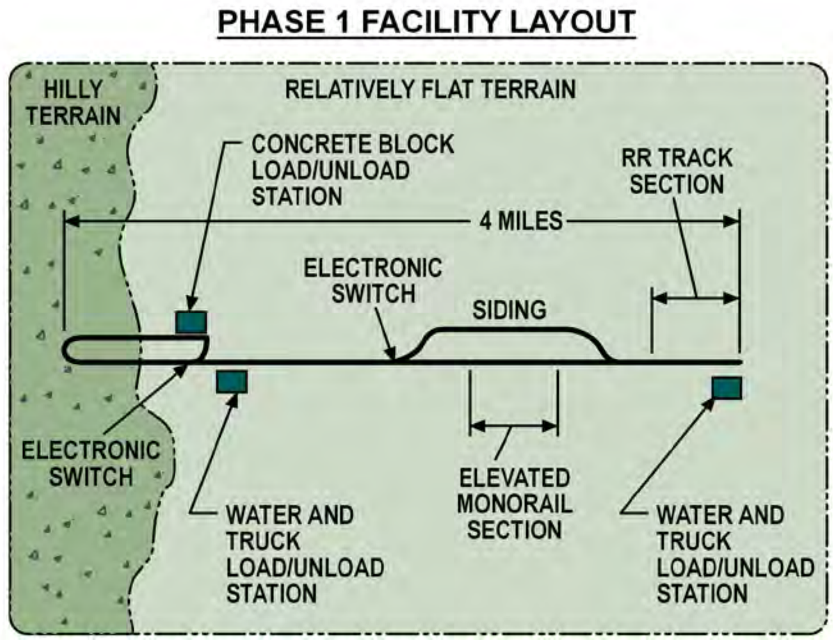
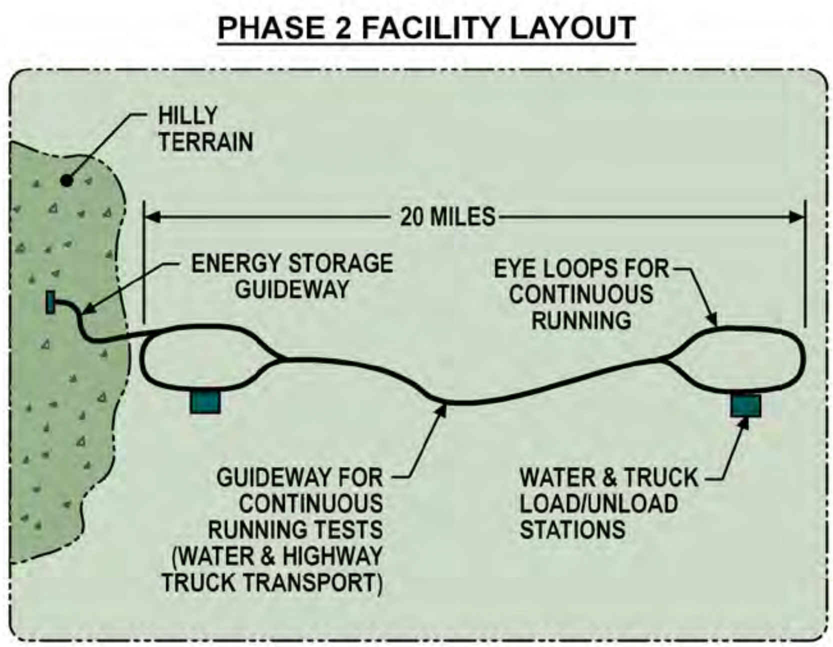


Figure 27


PHASE 1 FACILITY LAYOUT
HILLY TERRAIN
RELATIVELY FLAT TERRAIN
CONCRETE BLOCK LOAD/UNLOAD STATION
RR TRACK SECTION
4 MILES
ELECTRONIC SWITCH
SIDING
ELECTRONIC SWITCH
ELEVATED MONORAIL SECTION
WATER AND TRUCK LOAD/UNLOAD STATION
WATER AND TRUCK LOAD/UNLOAD STATION


PHASE 2 FACILITY LAYOUT
HILLY TERRAIN
20 MILES
ENERGY STORAGE GUIDEWAY
EYE LOOPS FOR CONTINUOUS RUNNING
GUIDEWAY FOR CONTINUOUS RUNNING TESTS (WATER & HIGHWAY TRUCK TRANSPORT)
WATER & TRUCK LOAD/UNLOAD STATIONS

7. Summary and Conclusions

There is a very large market for low cost, high efficiency systems that can store large amounts of electrical energy to be fed to the electrical grid during peak demand periods. The market is extremely large, both in the US and the World. Such systems could store thousands of Megawatt Hours daily generated from baseload coal and nuclear power plants during periods of low-demand by the grid, and feed it back to the grid during periods of high demand. This would eliminate the need for generating expensive power from natural gas peaking power plants.

A second major application for low cost, high efficiency, high volume electrical storage systems is to store power from renewable power sources, particularly wind and solar. The output from wind turbines and solar power plants is highly variable – the wind speed as only strong enough for power generation about 1/3rd of the time, and comes at highly variable and unpredictable times, often not matching power demand by the grid.

A third major application is to store large amounts of electrical energy to supply the grid in the event of accidents or sabotage that disable important power plants and /or transmission lines that would otherwise cause the grid to collapse over a very large area.

MAPS (MAglev Power System) is a new way to store large amounts of electrical energy at very low cost and very high electrical efficiency that has the capability for the 3 applications described above MAPS can store thousands of Megawatt Hours at very low cost, 2 to 3 cents per KWH stored, and has an output/input electrical efficiency of over 90% -- that is, for 100 kilowatt hours (KWH) of electrical energy fed into a MAPS storage facility, over 90 KWH is returned to the grid on demand.

MAPS stores electrical energy from the grid by using levitated and magnetically propelled Maglev vehicles to move heavy masses from a lower elevation to a higher elevation. The input electric energy to the Maglev propulsion system, which operates in the motor mode as it moves mass uphill, is stored as gravitation potential energy of the mass as it rests at its elevated location.

To convert the stored gravitation energy of the mass back to electric energy and return it to the grid, the Maglev vehicles moves the mass back to the lower elevation, with the Maglev propulsion system operating in the generator mode.

There are no mechanical friction losses in moving the storage masses uphill and downhill, the air drag losses are small, and the Maglev propulsion system is very efficient, resulting in a high electrical efficiency of 90% or better, output electrical energy deliver back to the gird, divided by input electric energy from the grid.

MAPS uses Maglev technology that has been developed as a practical, very reliable system for high speed transport of passengers. No breakthroughs are required – only adapting the basic existing Maglev technology for a new application.

A MAPS has important advantages compared to other electric energy storage systems. Pumped hydro, the most widely used energy storage system has a much lower output/input electrical efficiency. To deliver/KWH back to the grid, it must buy an input electrical energy of 1.5 KWH, losing 0.5 KWH in energy inefficiencies during the storage process to deliver 1 KWH back to the grid, MAPS only needs to buy at most 1.1 KWH of electrical enegy, losing just 0.1 KWH, because of it much greater storage efficiency.

Moreover, pumped hydro has environmental restrictions and problems, and is very limited where it can be sited. In contrast, MAPS has far fewer environmental problems, and can be sited at a much wider range of locations. Similarly, MAPS is more efficient than the compressed air storage systems, and can be sited at a much wider range of locations.

Other energy storage systems, i.e., batteries, flywheels, superconducting magnetic energy Storage (SMES) are much more expensive per KWH stored than MAPS, and are only suited for storing relatively small amounts of electrical energy for dynamic stabilization of the electrical grid in the event of frequency and for mismatches in phase. They are not practical for storage of large blocks of electric power.

MAPS can be demonstrated and certified for commercial use relatively quickly. The proposed SUMMIT (SUperconducting Maglev Multi Integrated Testing) program would demonstrate the operating performance capability of full scale MAPS vehicles carrying 100 tonne masses uphill for an elevation increase of several thousand feet. Efficiency, speed, storage and retrieval capability – all would be demonstrated. Phase 1 of the SUMMIT programs would demonstrate all capabilities of the MAPS system in 3 years at a program cost off 160 million dollars.

The Phase 1 program would be followed by a Phase 2 program in which all of the MAPS system components, vehicles, guideway, handling equipment, power conditioning equipment would be continuously tested for a period of 2 years, at a cost of 170 million dollars, to demonstrate system reliability and establish maintenance requirements.

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Glossary

Cryostat – A thermally insulated structure that encloses equipment that is maintained at very low temperatures, e.g., a superconducting magnet.

I^2R Losses – Electrical losses due to the electrical resistance of a conductor that carries electric current.

KWH – Electric energy equivalent to 1000 watts per hour of operation.

Linear Synchronous Motor – A motor in which the speed of the object propelled along a linear guideway is controlled by the frequency of the AC current supplied to the linear motor.

Maglev – Magnetic Levitation – A method of magnetically levitating and moving objects without physical contact with the ground.

MAPS – Maglev Power System is a new approach for electrical energy storage by moving heavy masses up and downhill, storing the electrical energy as gravitational potential energy.

MWH – Electric energy equivalent to 1 million watts per hour of operation.

Polymer Concrete – Mixture of concrete material with polyester monomer, which when poured, solidifies to form solid concrete that is 4 times stronger in tension and compression than ordinary concrete.

Quadrupole – A magnet configuration that has 4 poles, 2 North and 2 South, instead of the 2 pole North-South configuration of dipole magnets.

SMES – Superconducting Magnetic Energy Storage – A method to store electrical energy as the magnetic field energy of a superconducting winding.

SUMMIT – Proposed facility to test the operation of Maglev vehicles for energy storage, transport of highway trucks, and long-distance transport of water..

Superconductivity – the ability of certain types of materials to carry large amounts of electrical current, e.g., millions of amps per square centimeter, without electrical losses when cooled to temperature well below ambient temperature.

T**onne** – 1 metric ton equals 1000 kilograms, equivalent to 2208 pounds, or 1.1 short tons.

T**ransrapid** – Maglev passenger transport system developed by Germany. Based on attractive force between conventional ambient temperature, non- superconducting magnets on the Maglev vehicle and iron rails on the guideway. Very small clearance, 3/8 inch, between vehicle and guideway, compared to 4 inches for superconducting Maglev. Also, Transrapid vehicles must have their electromagnetic current continuously adjusted on a time scale of several thousandths of a second, to prevent vehicles from hitting the guideway. Superconducting Maglev, in contrast, is inherently stable and self-controlling – no adjustment of current is necessary.

YBCO Superconductor – New superconductor that operates at much higher temperature than old niobium titanium superconductor, e.g. 77 degrees instead of 4 degrees Kelvin. Yttrium barium copper oxide, abbreviated YBCO, is a crystalline chemical compound with the formula $YBa_2Cu_3O_7$. This material, achieved prominence because it was the first material to achieve superconductivity above the boiling point of nitrogen because of this property, much simpler refrigeration and thermal insulation can be used to cool YBCO superconductor.

Key Personnel and Contact Information

Dr. James R. Powell will serve as Chief Scientist and Co-Principal Investigator for the project. Dr. Powell is the co-inventor of and holds several patents in the superconducting maglev technology. He has over 50 years of experience in scientific and engineering research programs including decades of experience with Brookhaven National Laboratory (BNL). He successfully led a $12 million U.S. Department of Transportation funded project for superconducting maglev transportation component research and development. He received his B.S. in Chemical Engineering from Carnegie Institute of Technology and his Sc.D. in Nuclear Engineering from the Massachusetts Institute of Technology.

Dr. Gordon Danby will serve as Co-Principal Investigator for the project. He has over 50 years of experience in scientific and engineering research programs including decades of experience with Brookhaven National Laboratory. He retired as a Senior Physicist at BNL, where he worked on the theory and experimental development of accelerators and magnetic detectors for the study of basic properties of matter. Dr. Danby is also a pioneer of Magnetic Resonance Imaging (MRI). His concepts formed the basis for one of the world's first commercially successful medical scanners. Both Dr. Powell's and Dr. Danby's inventions, including the inductive levitation and stabilization guideway, null flux geometry, and the Linear Synchronous Motor for vehicle propulsion, have been adopted through the world, and form the basis for the Tokyo to Osaka maglev route.

Mr. James C. Jordan is President of Interstate Maglev Project, LLC. He previously led an award-winning program for DOE as President of the Radioactive Isolation Consortium. Mr. Jordan founded and raised $80 million to create a pioneering Earth Science Data Network now located at Columbia University. Mr. Jordan retired from the Navy and became a senior policy advisor to Senator John C. Stennis. In this capacity, Mr. Jordan was a Senate staff leader in energy, environmental, and transportation policy. Mr. Jordan is Executive Vice President of Maglev-2000 and President of the Interstate Maglev Project, LLC. He holds an MBA, Harvard Business School; is a Distinguished Graduate of the Industrial College of the Armed Forces at the National Defense University; and earned a B.A. from the University of North Carolina, Chapel Hill. james.jordan@magneticglide.com

Mr. Robert J. Coullahan, CEM, CPP, CBCP is President of Readiness Resource Group (RRG). He previously served 20 years with Science Applications International Corporation (SAIC) where he was Senior Vice President. He has over 30 years of federal systems integration, advanced technology RDT&E, studies and analysis and national security emergency preparedness program experience. He is a US Army veteran, graduate of the University of California and holds the M.S. and M.A. degrees from The George Washington University. coullahan@readinessresource.net

Dr. F.C. (Bud) Griffis is Professor of Construction Engineering and Management in the Department of Civil Engineering Polytechnic Institute of New York University. He teaches courses in construction engineering, management, leadership, planning, capital budgeting, and risk management. During the past five years, he has been heavily involved in research into the second generation Magnetic Levitation Vehicle and their guideways. He holds a B.S. degree from the U.S. Military Academy at West Point, two Masters degrees (one in Construction Engineering and one in Operations Research) and a Ph.D. in Civil Engineering (Construction) from Oklahoma State University. He is also a graduate of the U.S. Army War College. In 2007, he received the Golden Eagle Award from the Society of American Military Engineers. griffis@poly.edu