Maglev Freight Conveyor Systems

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Introduction

This paper is submitted in response to a request arising out of a meeting with high level representatives of DOT/FRA, MARAD and the National Transportation Policy and Revenue Study Commission to provide the commission with information about the ECCO Project as a potential solution to growing congestion and pollution in and around the ports of our nation.

Cities naturally grow up around ports, reducing availability of low cost land for port expansion. Inevitably, the result is traffic congestion along road systems originally intended for local deliveries and commuters. It makes sense to move containers to inland locations for processing and transport to their final destinations. A system to quickly and effectively move containers from the Port is needed, and such a system is the Electric Cargo Conveyor or ECCO system. ECCO does not rely on thousands of Diesel trucks congesting roadways to move containers, but rather uses a small footprint, grade-separated, elevated cargo conveyor, powered by the existing electrical grid. Being all electric, this system emits no pollution along its path and can directly utilize renewable energy sources.

ECCO presently uses a form of maglev (magnetic levitation) technology different than the maglev technology associated with numerous passenger systems proposed and built over the last half century. The ECCO system is an American maglev technology invented by Lawrence Livermore National Laboratory, licensed and prototyped by General Atomics (GA) of San Diego, CA. The ECCO shows such promise that the Office of Naval Research investigating military applications of freight movement, states: “The most likely first commercial application of maglev technology in the United States will be a freight conveyor.”[1]

This paper describes background and public policy considerations that went into the ECCO concept development, including the economic, social and institutional benefits of implementing such a system. Particular benefits of the ECCO system are reduction of congestion, air, and noise pollution, higher container throughputs than road or rail, potential to pay for itself with the farebox, and a long predicted operational lifetime.

Background of ECCO Development

California State University, Long Beach (CSULB), which is adjacent to the Port of Los Angeles/Long Beach (LA/LB), originated the ECCO concept in response to the community’s need for reducing congestion and pollution due to container movement at the Port. Approximately 43% of the containers coming through this Port go through Southern California and continue on to the rest of the country. The projected increase in Port activity of 8% per year infers a healthy Southern California goods movement economy for years to come. The ECCO architecture offers a container throughput capacity exceeding those of conventional road and rail to allow such economic growth. Alternative proposals to enhance port throughput have involved expansions to conventional road and rail infrastructure, which only increases congestion and mobile source emissions, including NO_X, carbon monoxide, greenhouse gases, and Diesel Particulate Emissions, or DPEs.

Catalytic conversion and adoption of alternative fuel combustion engine technologies will certainly reduce emissions; unfortunately, increasing the number of container moves due to port growth off-sets these gains. Additionally, these emission reduction technologies do not resolve the problem of increased congestion leading to lost productivity, which can be measured in billions of dollars per year.[2] It is understandable that communities near the Port and along rail and road corridors connected to the Port have expressed health and safety concerns regarding port expansion and its associated transportation infrastructure. Port communities, environmental groups, business leaders and elected officials have all expressed considerable interest in the ECCO system as a potential solution for reducing the pollution and congestion around the ports.

Figure 1. ECCO Will Greatly Reduce I-710 Truck Traffic from Ports of LA/LB.

When CSULB first developed the ECCO concept a few years ago, the only commercial maglev system in the world was the Shanghai maglev that uses a technology developed by TransRapid of Germany. The University contracted TransRapid to determine if moving shipping containers with maglev was possible. They had not previously considered the many advantages that freight transport offered over passenger transport, such as having a known ridership requiring few, fixed destinations with a willingness to travel anytime, 24/7. TransRapid confirmed CSULB's position that containers were a more predictable and likely more profitable ridership than passenger transport provides; they determined that container movement was not only feasible but would require only slight changes to their present passenger system design.

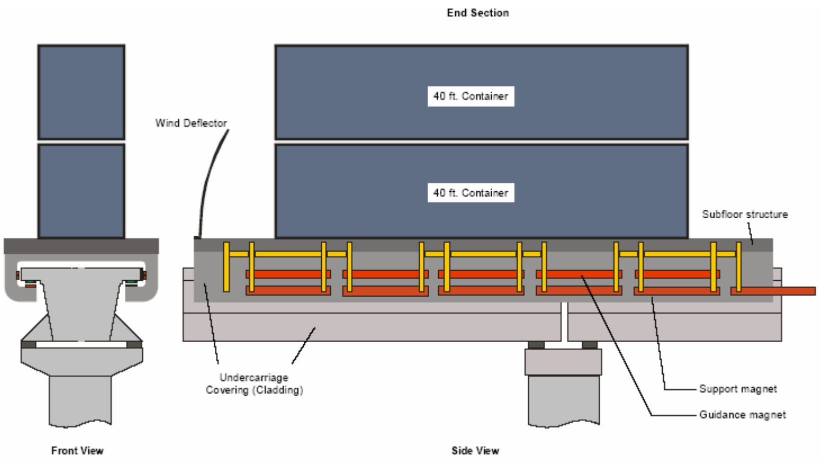

Figure 2. TransRapid's Design Response to CSULB Container Mover Concept (2005)

TransRapid began development some 50 years ago on what is referred to as an *Electro-Magnetic* system. Batteries on board such a system energize powerful electromagnets wrapped around the guideway which lift the carriage up to ferrous metal plates on the bottom of the guideway. Levitation is accomplished by electronic feedback balancing the magnetic *attractive* force upwards with the gravitational force downwards. Desk toys that "float" model globes employ a similar concept, but in the case of the ECCO transportation system, the floating carriage with container is moving on the guideway at 90 miles per hour.

The most recent form of ECCO concept implementation utilizes a magnetic levitation technology developed in the United States. GA has built the only operational full-scale maglev test track in the United States, and the first full-scale cargo container chassis. The levitation technology is an *Electro-Dynamic* system which pushes off the guideway instead being attracted to it. While this technology has been appealing for decades due to its simplicity and ruggedness resulting from its utilization of passive levitation, implementation has been possible only recently due to improvements in permanent magnet material residual field strength. In this approach, levitation is accomplished by moving permanent magnets mounted on the underside of the carriage over an electrically conducting metal surface such as copper or aluminum. This forward movement produces currents in the metal which in turn produce a magnetic field *opposing* the on-board magnets causing the carriage to lift off and levitate about an inch above the guideway. Just as an airplane uses wheels to reach forward speed until aerodynamic lift is achieved, the ECCO uses wheels until magnetic lift is achieved—the speed of a brisk walk—after which it can accelerate to speeds of up to 90 miles per hour or more. As compared with the older Electro-Magnetic technology used in other maglev systems around the world, the GA Electro-Dynamic technology can reduce vehicle costs and weight by eliminating the amount of electrical equipment that must be carried on board the vehicle. This is an especially important consideration for a cargo-carrying system transporting heavy loads. Another appealing feature of Electro-Dynamic maglev technology is that it increases the gap between the guideway and vehicle, reducing the precision with which the guideway must be manufactured and maintained.

Figure 3. World's First Maglev Container Move at General Atomics San Diego, CA, June 2006.

To date, all forms of the ECCO concept use a Linear Synchronous Motor (LSM) mounted on the guideway to propel the chassis forward; which can be conceived of as similar to a typical round electric motor, unwound and laid lengthwise along the guideway to form a "linear motor."

In 2005, CSULB demonstrated the **feasibility** of moving containers on an ECCO system; in 2006, CSULB in conjunction with GA demonstrated the **reality** of the ECCO system with a full-scale container-carrying prototype. The photograph shows a twenty foot container (1 TEU) on the GA maglev test track. Note that there is no mechanical contact of the container vehicle with the guideway, and furthermore there is no motor or operator on board.

Figure 4. ECCO Is Contact-Free, Resulting in Very Low Maintenance Costs.

Since the system is contact-free when levitated, this assures low lifecycle maintenance costs, an important factor in evaluating freight transport systems. High maintenance costs over decades of road and rail usage add greatly to these systems' total costs. The expected operational life for the ECCO civil infrastructure is greater than 75 years.

ECCO Reduces Urban Congestion

Floating on a magnetic field rather than using wheels, ECCO exhibits enhanced flexibility over road and rail options via two inherent aspects; elevated infrastructure and superior grade climbing ability. When containers are placed on a rail car the entire weight is concentrated on a small area of the track. The same container loaded onto a truck chassis puts all its weight on the area where the tires are in contact with the road. In both cases the container's weight is focused onto small areas of rail or road and generates a moving pressure wave on the rail or road that requires a significant supporting infrastructure. This pressure wave can account for misalignment of rails, the unevenness of cement plates on highways, and washboards on asphalt surface streets. ECCO distributes a container's weight over a large bank of magnets whose surface area is thousands of times larger than the corresponding weight-bearing points of road or rail, thus eliminating the severe pressure gradients of wheeled vehicles. This produces minimum stress on guideway infrastructure, and reduces the size and cost of structures needed to elevate the system. The ECCO "footprint" (land requirement) is a series of reinforced concrete posts approximately one hundred feet apart to support the guideway. This reduced footprint permits the use of a number of existing rights-of-way, such as freeway medians, power line corridors, land adjacent to riverbeds, elevated over conventional rail, etc.

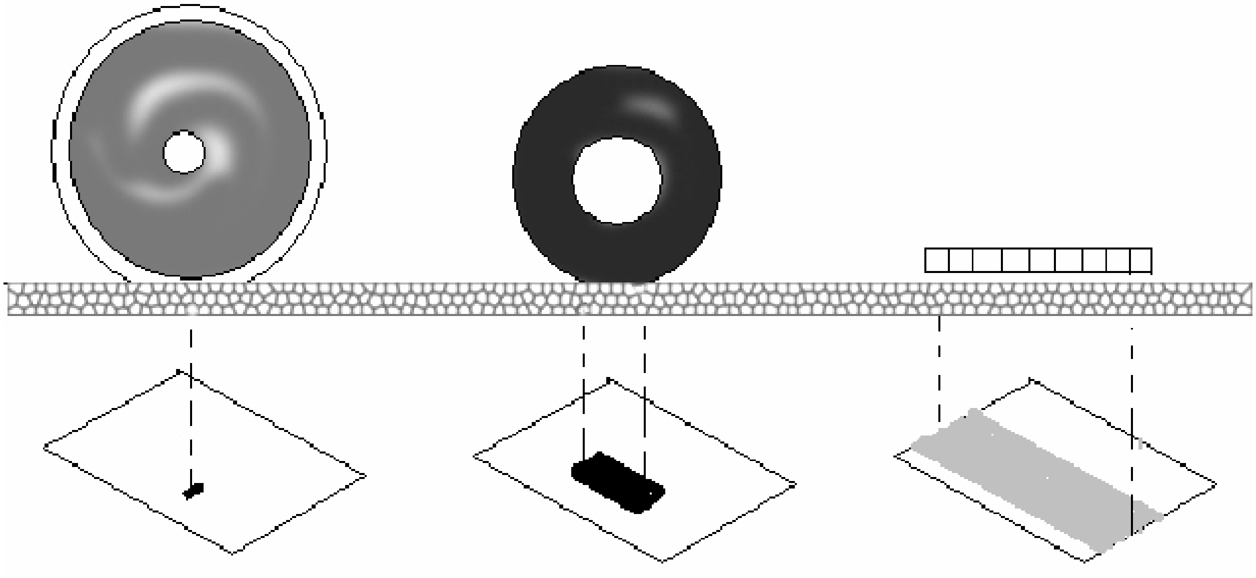

Figure 5. ECCO Replaces Wheels with Arrays of Magnets which Greatly Reduces Stress on the Guideway.

Because an elevated guideway is the preferred architecture for the ECCO system, its superior grade climbing ability allows it to conform to existing geography and infrastructure. By using the linear synchronous motor built into the ECCO guideway, denser motor windings can be employed in guideway sections where extra power is needed, such as in climbing steep terrain or gaining height for water and grade crossings. This makes the climbing of uphill grades more efficient than the use of conventional motors on wheeled vehicles, which must be sized to climb the steepest grades even though they are infrequently used for hill-climbing. On downhill grades, the same dense motor windings in the ECCO guideway enable regenerative braking, where much of the vehicle's kinetic energy can be recaptured as opposed to being burned off in the form of wasted heat energy by conventional braking systems.

Even with appropriately sized conventional diesel power plants, rail-based transport can only climb a 3% grade and road-based transport a 6% grade, whereas ECCO can climb a much steeper 10% grade or more. An awkward issue faced by planners laying out a road or a rail system in an urban infrastructure is the approach to gain height for crossing navigable waterways and other transport thoroughfares. Large areas of at-grade land are required to bring the road or rail up to, and down from the necessary elevation. ECCO's steep climbing ability and its naturally elevated configuration provide planners with a flexible means of positioning high throughput container transport on top of an over-burdened urban road and rail infrastructure.

Anytime a new form of transport is introduced into a community with an already congested infrastructure and complex economy, like ports and cities, compatibility with existing conditions must be considered. The figure demonstrates how the elevated ECCO might function at a port terminal with a main, elevated conveyor loop running parallel to a terminal's perimeter over existing rail and road, and a switched siding that quickly comes down to grade level for loading and unloading the containers in the terminal. The sketch shows that ECCO uses typical truck or rail load/unload labor and equipment processes. The process and equipment depicted are not necessarily for a high-throughput system.

Figure 6. ECCO Is Compatible with Existing Road and Rail Infrastructure

Urban congestion caused by rail-based transport is somewhat different from congestion produced by trucks on the highway. For container moves by rail to be cost competitive with trucks, several containers must be moved on a single train. A typical train segment can be a half-mile in length or longer. Congestion (and concomitant pollution) caused by a train slowly moving through numerous grade crossings entails roadway vehicles idling at these crossings and cannot be easily quantified.

ECCO Reduces Pollution

Compared to the use of drayage trucks for transporting containers, the ECCO system can greatly reduce emissions of oxides of nitrogen (NO_X), greenhouse gases such as carbon dioxide (CO_2), and Diesel Particulate Emissions or DPE. Reducing all of these emissions is a high priority, evidenced by California's recent allocation of $1 billion in bond proceeds to mitigate the emissions resulting from goods movement. DPE is different from gaseous pollutants in that it is concentrated in areas where diesel engines operate such as the port, truck/train intermodals, and along freeway and rail corridors. The effects of DPE are devastating. More than thirty (30) human epidemiological studies have found that diesel exhaust increases cancer risks; and one 1999 California study found that diesel exhaust is responsible for seventy (70) percent of cancer risks from air pollution[3]. Recently, the danger of having homes and schools close to sources of DPE has been recognized[4]. The ECCO container transport approach can use electricity generated by modern natural gas fired power plants, which emit very low NO_X (as little as 0.1 grams/kWhr – 10 to 20 times less per unit of energy consumed than typical container trucks) and emits *zero* DPE.

A quantitative discussion allows a visualization of the pollution reduction benefits of an ECCO conveyor system in an urban area. Assume first a scenario wherein 1000 (500 in both directions) 30 ton containers are moved per day (200,000 containers per year) through 10 miles of typical urban traffic using trucks with a 32 year age distribution peaking at around 10 years. The California Air Resources Board (CARB) EMFAC2007 model predicts baseline levels for the assumed scenario of DPE and NO_X as shown in the following table. The baseline ECCO system for this scenario is a single bidirectional guideway system covering the same distance with a capacity exceeding 1000 containers a day, moving containers at speeds averaging 90 mph between two terminals. The ECCO local pollution production estimates are shown in the table below (based on stationary electrical plant local pollution for generating the energy required for moving the 1000 containers per day).

Many communities are currently proposing mandatory replacement of older polluting trucks with newer trucks having expensive pollution mitigation equipment. Although timely, this measure does not address the problem of traffic congestion and the resultant increase in pollutant levels.

	Diesel Particulate Emission, PM_{30}	**Oxides of Nitrogen NO_X**
Baseline Truck {typical truck fleet moving 200,000 containers/year, 20 miles round trip }	6.9 tons/year	124.4 tons/year
New Truck {new truck fleet moving 200,000 containers/year, 20 miles round trip }	1.8 tons/year	48.5 tons/year
ECCO System {200,000 containers/year, 20 miles round trip}	0.0 tons/year	2.8 tons/year

Table 1 – ECCO Offers Substantial Pollution Reduction Over Truck Transport.

ECCO Reduces Dependence on Fossil Fuels

ECCO is projected to be at least (and potentially several times) as energy efficient as using container trucks. A typical container truck carrying a 20-ton load and achieving a fuel economy of 5 miles per gallon achieves 100 ton-miles of cargo transport per gallon of diesel fuel consumed. Based on an equivalent energy content of 40 kWhr per gallon of diesel fuel, this works out to 2.5 ton-miles per kWhr. GA has already achieved this level of energy efficiency on its ECCO test track in San Diego, and believes that future improvements could increase ECCO efficiency several times again.

Independently of fuel efficiency benefits, ECCO provides greater flexibility with respect to energy source. ECCO can use energy produced with renewable hydroelectric, wind, and solar power, as well as the new generation of nuclear power plants—completely eliminating cradle-to-grave emissions and reducing dependence on fossil fuels. Natural gas-fired power plants, although fossil fuel based, are significantly cleaner than oil or coal power plants, and can also be a source of clean power for ECCO.

As previously explained, the motor of the ECCO container carriage is in the guideway. Electrical power is conserved by powering only those sections of the guideway where the ECCO carriage is traveling. This segmented powering design format has a number of additional safety and control advantages, as described in the next section.

ECCO Potential for Increased Homeland Security and Transportation Safety

The removal of container traffic intended for remote locations from the urban highway infrastructure and placing them on ECCO will improve traffic flow, increase productivity, and improve highway safety. Being entirely automated and grade-separated, the ECCO system has important safety benefits. The segmented linear synchronous motor in the guideway is operated by activating alternate sections of the guideway, which achieves a safe separation between container carriages as well as increasing the system's energy efficiency.

An elevated, continuously moving container conveyor is implicitly more secure than a grounded, stationary container. The ECCO system includes state-of-the-art closed circuit TV monitoring systems along the entire length of the guideway. Since the field of view for these systems is limited to the upper and lower portions of the guideway where the only motion is scheduled container traffic, any unscheduled movement or anomalous changes are recognized by machine vision software which can generate an alarm for real-time scrutiny by an ECCO system operator.

In addition to external monitoring along the system, unmanned ECCO carriages can have their contents examined by X-ray and neutron activation for contraband—while in transit. Present container X-ray imaging and active neutron scanning processes require a container be removed from the goods movement path for examination in facilities where humans are isolated from radiation. Every container moving along the ECCO conveyor, however, can pass through a shielded, active radiation security portal, thus providing a 100% safe and secure screening process. Again, machine vision software automates the inspection process and those images flagged for further analysis can be viewed at remote locations via the internet. The ECCO lends itself ideally to automated security inspection processes.

ECCO Profitability Pays for Itself Through the Farebox

The first application of the ECCO was defined in a Port of LA/LB contract with GA using CSULB's ECCO concept supporting the system architecture[5]. This study produced a preliminary cost estimate for a 4.7 mile ECCO system between the Port and an Intermodal Container Transfer Facility (ICTF) near the Port moving 5000+ containers per day. The team of CSULB, GA, and nationally recognized civil engineering and railroad signaling safety companies determined the cost of a totally elevated Port system to be $90M/mile for a dual guideway system. This is considerably less than a trenched rail corridor ($125M/mile) or a new, at-grade freeway ($150M/mile) which could carry the same container volume, but at the cost of slashing though the community and environment. In addition, the operating cost of the port ECCO system is projected to be $2.20 per container-mile, of which $0.80 is the cost of electricity.

The present cost of trucking containers from the Port to the major ICTFs along the I-710 and beyond is a $50 base fee plus around $5/mile. This amount includes the driver's labor, tractor and chassis maintenance, fuel, taxes and licensing, amortized cost of the equipment, and profit. The truck drayage trip from the port to the ICTF specified in the referenced ECCO study (4.7 miles) costs from $65 to $80. A cost comparison of conventional truck drayage with ECCO requires the amortized cost of constructing the ECCO be added to the operational cost. Assuming that funding is provided by a bonding agency or by a Public/Private Partnership (PPP, to be discussed in the next section), the amortized cost per container ranges from $26 to $30—depending upon financing options.

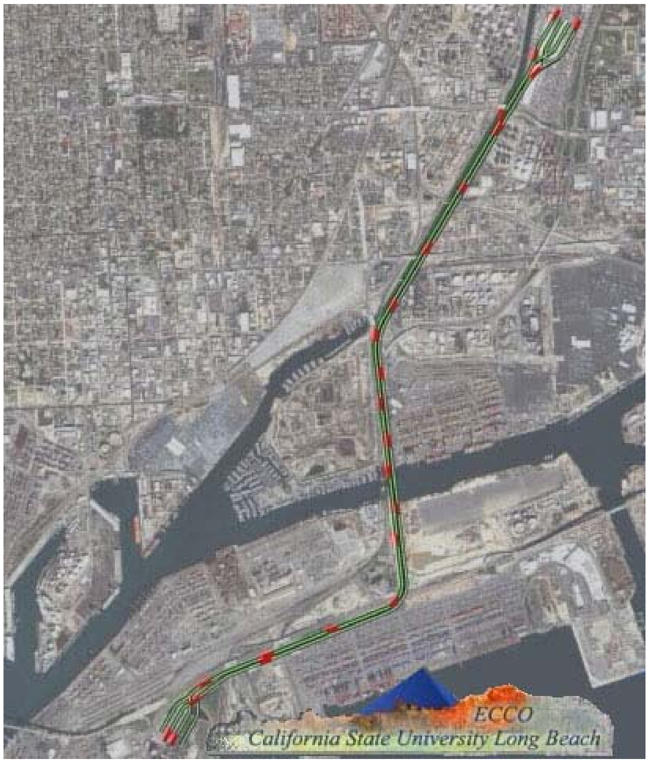

Figure 7 Alignment for Port of LA/ECCO Project

Hence, the total cost per container of the "turn-key" ECCO system, including guideways, energy, terminals, security, operating personnel, and "rolling stock" comes to under $40. Neither estimate (for truck drayage or ECCO) includes load-on and load-off expense, assumed to be the same for both cases. Charging $60 for an ECCO move that reduces truck presence on highways, is non-polluting, quiet, energy efficient, and secure should pay off the debt of construction in less than eight (8) years and provide a very attractive return on investment. The financial benefits of the ECCO are expected to attract private investors.

ECCO Is Ideally Suited for Public/Private Partnership

Public/Private Partnerships (PPPs) are envisioned as the preferred form of constructing ECCO systems in urban areas, similar to the manner by which toll lanes on existing freeways have been built and financed. With this model, a public infrastructure owner awards a franchise to a private sector partner to Design, Build, Finance, and Operate (DBFO) a transportation project for a pre-determined concession period. In exchange, the private sector partner has the right to collect all revenues generated by the project during the franchise period. ECCO's ridership (containers) is more predictable and reliable than are toll lane customers, hence the financial options are potentially very attractive to private investors. The public sector may provide limited financial assistance, such as development period cost-sharing, right-of-way provisions, or limited revenue guarantees, but the private sector partner bears the revenue risk, and determines that the funds generated will be adequate to paying off the underlying project loans and interest and make a fair profit on the investment of time, expertise, and money.

DBFO concessions can be awarded for the construction of a new asset or for the modernization, upgrade, or expansion of an existing facility. DBFO concessions often extend for a period of 25 to 30 years or even longer, and are awarded under competitive bidding conditions. Under a DBFO approach, the ownership of all assets, both existing and new, remains with the city/state government or transportation authority. However, the government agencies usually stipulate maintenance protocols and specific improvements to be made over the franchise period to ensure that the assets are properly used and maintained during the initial concession period and are in good condition when the period is over.

Case Study: ECCO Relation to Energy and Energy Distribution

As an example of how the ECCO concept can influence urban planning, consider a possible relationship of a hypothetical urban ECCO system with an urban electric power grid. ECCO's additional use of the grid, of course, impacts the capacity of an urban area's electrical distribution system. Consider in addition the difficulty of building new electrical generating plants near cities. Such plants can be built and operated effectively in isolated areas away from urban regions, but this option traditionally has not been exercised because of the expense of requisite power distribution lines to deliver power to the city from outlying plants. The postulated ECCO system's ability to share the same rights-of-way as power distribution lines is pertinent here. A fundamental premise of this paper is that the ECCO runs on an elevated alignment through the city, reducing congestion and simultanteously moving freight to a remote area for container processing and storage; this is the same land use requirement as that for remote power plants. Generating power in the same location as the (remote) inland terminus allows the ECCO route to be the backbone of the power grid and vice versa.

An additional benefit of this right-of-way sharing approach is the possible elimination of transmission line towers in these swaths of land by shielding the electrical lines in conducting cylinders—gas insulated transmission lines (GITLs), allowing these lines to transmit power more effectively, and to require less space.[6] Many urban communities would prefer to consolidate overhead lines into shielded line enclosures; but the cost of these enclosures is significant. Moreover, due to the necessity for maintenance, these enclosures are still visible at ground level. The integration of gas-insulated transmission lines into ECCO guideways could simultaneously reduce the cost of consolidating overhead electrical power transmission and allow existing and future transmission line rights-of-way to be used for other purposes, such as goods movement corridors.

New Paradigm for Container Movement

Maglev technology is a solution that can help alleviate the problems created by the technology which is responsible for the congestion and pollution many urban areas face today. This technology facilitates the needed balance between more and better jobs inherent in an expanding economy and quiet, clean, and congestion-free neighborhoods. Thus, ECCO's slogan, attributed to Albert Einstein: "One cannot solve problems with the same technologies that caused them."

End notes:

[1] The Impact of Magnetic Levitation Technology Development for Civilian and Military Utilization Final Report. (Sept. 2006 Sandia/Los Alamos Labs Study). Sponsored by the Office of Naval Research.

[2] The 2005 Urban Mobility Report. http//mobility.tamu/ums/report/

[3] Bailey Diane et. all Harboring Pollution The Dirty Truth About U.S. Ports, Natural Resources Defense Council Mar. 2004. http://www.nrdc.org/air/pollution/ports/ports2.pdf

[4]"Effect of exposure to traffic on lung development from 10 to 18 years of age", by Gauderman, et.al. dated 1/26/2007 www.thelancet.com

[5] Conceptual Design Study For The Electric Cargo COnveyor (ECCO) System . http://www.portoflosangeles.org/DOC/REPORT_ECCO_102706.pdf

[6] A Basic Study on Hybrid Gas Insulated Transmission Line (H-GIL) (Part 3): Estimation of Breakdown Characteristics and Transmission Line Properties CRIEPI Report No. T95048, 1996 http://criepi.denken.or.jp/en/e_publication/a1996/96seika28.html