Maglev and Linear Motors for Goods Movement

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Presentation Topics

• Background: Application of Electromagnetic Technology to Goods Movement

• Maglev Systems For Goods Movement

• Linear Induction Motor Rail ("LIM-Rail™") Systems for Goods Movement

• Conclusions
Background: Application of Electromagnetic Technology to Goods Movement
Critical Goods Movement Issues Facing CA

- Environmental impact, especially emissions of NOx and diesel particulate matter
- Transportation impacts in vicinity of ports
  - Traffic congestion
  - Noise
  - Road damage
- Factors relating to the efficiency of goods movement
  - Velocity – speed of moving cargo thru distribution system
  - Throughput – volume of cargo moving thru distribution system
  - Reliability – consistent, predictable timing of cargo movement
  - Congestion – delays in goods movement thru system
Electromagnetic Technologies Available for Goods Movement Application

- **Maglev**
  - Vehicles magnetically levitated above specially-built guideways
  - Benefits: clean, efficient, quiet – and very high speeds are possible
  - Practical where new infrastructure is required for higher throughput

- **Linear Motor Technology**
  - Means of providing forward propulsion in most maglev systems
  - Also used in existing wheeled vehicles (e.g., JFK AirTrain™)
  - Other applications using existing infrastructure are possible
Comparison of Maglev and Linear Motor Technology Approaches

• Maglev
  - Zero emissions at point of operation
  - Operating on new, dedicated, above-grade guideways, can dramatically improve velocity and throughput
  - Greatest potential to reduce noise and congestion
  - Economically competitive where new infrastructure is required to meet goods movement demands

• Linear Induction Motor Rail ("LIM-Rail") systems
  - Also a zero emission solution
  - Compatible with existing rail infrastructure
  - Limited ability to address velocity and throughput, but can potentially achieve near term emissions benefits and set the stage for longer term infrastructure expansion using maglev
General Atomics & Affiliates

Founded: 1955
Employees: 4200 Worldwide
Major Businesses:

Defense
- UAV Systems
- Advanced Sensors
- Naval Ship Electrification
- Weapons Destruction
- EMALS
- AAG

Energy
- Fusion
- Uranium Mining & Conversion
- Reactor Development

Transportation
- Maglev Systems
- Streetcar Refurbishment
- Mining Truck Drives
- Track Refurbishment
GA Electromagnetic Project Experience

FTA Urban Maglev
California-Nevada High-Speed Maglev
Air Force Holloman High-Speed Maglev
Navy Electromagnetic Aircraft Launch System
General Atomics Maglev Activities

• High-speed maglev
  ➢ Partner in “American Magline Group,” offering German “Transrapid” technology in U.S.
    • First fully operational system in Shanghai has transported 6.6 million passengers at speeds up to 267 mph, with 99.85% reliability
    • In study phase for proposed link between Anaheim and Las Vegas
  ➢ Supplier of power components

• Urban maglev
  ➢ Lawrence Livermore developed “passive maglev” technology
  ➢ GA-led cost-shared program, supported by the FTA for the past 7 years
  ➢ Attractive for urban, short distance routes
  ➢ Recently seen as an equally attractive solution for goods movement
Features of GA Passive Maglev Technology

• No active power system on vehicle – only permanent magnets
  ➢ Lighter, cheaper, more efficient vehicle design
  ➢ Allows use of guideway tracks that are lighter, cheaper, and less intrusive

• “Halbach Array” magnet configuration adds to benefits
  ➢ Increased magnetic field strength
  ➢ Very low magnetic fields in passenger compartments and near stations (well below allowable standards)
  ➢ Larger air-gap enables less expensive guideway construction
General Atomics Maglev Test Track

• San Diego, CA
  ➢ Completed in September 2004
  ➢ 400 ft. long
  ➢ Highly instrumented test vehicle to validate ride quality and system performance
  ➢ *Only full-scale, functional maglev system in U.S.*
Electromagnetic Aircraft Launch System (EMALS)
Maglev Systems for Goods Movement
ECCO*: Maglev for Goods Movement

- Same maglev principle used in passenger transport
- Joint GA/Cal State Long Beach-CCDoTT study
- Cargo containers can be transported in multi-unit trains ("consists") or individually
- Feasibility demonstrated on GA test track in mid-2006

* ECCO = Electric Cargo COnveyor
<table>
<thead>
<tr>
<th>Description</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Container trips per day:</td>
<td>5,000 (2,500 per direction)</td>
</tr>
<tr>
<td>Container size:</td>
<td>Up to 40’</td>
</tr>
<tr>
<td>Container weight:</td>
<td>30,482 Kg (67,200 lbs)</td>
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<tr>
<td>Operation hours:</td>
<td>24 hours</td>
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</table>
## ECCO Operational Parameters

- **Maximum Speed:** 145 kmph (90 mph)
- **Acceleration:** 1.6 m/s²
- **Trip time (high-speed section):** 3.5 min.
- **Average speed:** ~122 kmph (~80 mph)
- **Headway:** 20 seconds
- **Maximum g loading:**
  - Longitudinal, vertical, lateral (nominal): 0.16 g (1.6 m/s²)
  - Longitudinal (emergency): 0.36 g (3.6 m/s²)
- **External Noise Limit:** 72 dBA
- **Availability:** > 99%
Potential Maglev Alignments at Ports of Los Angeles & Long Beach

- Link ports with long-haul freight (truck & rail) terminals
- Case Study considered during PoLA study: link POLA with SCIG
- Length: 4.7 miles
## ECCO Development Schedule

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
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<tr>
<td>Site specific/Detail Engineering</td>
<td></td>
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<td></td>
<td>ECCO Cargo Maglev operational</td>
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<td>Construction</td>
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<tr>
<td>Commissioning</td>
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</tr>
<tr>
<td>Operation</td>
<td></td>
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</table>
## ECCO Maglev Costs*

<table>
<thead>
<tr>
<th>Maglev System Element</th>
<th>Cost/Mile ($)</th>
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<tbody>
<tr>
<td>Guideways and civil structures</td>
<td>10,000,000</td>
</tr>
<tr>
<td>Maglev track and propulsion components</td>
<td>20,500,000</td>
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<tr>
<td>Electrical energy supply equipment</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>45,500,000</strong></td>
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</table>

(Maglev cargo vehicles are estimated to cost an additional $800,000 each)

*Costs are estimates per mile of single track, extrapolated from General Atomics Conceptual Design Study for the ECCO System, Port of Los Angeles, Final Report dated 27 October 2006
## ECCO Operations Cost Estimate

<table>
<thead>
<tr>
<th>Annual Operations Costs</th>
<th>Personnel</th>
<th>Salary &amp; Benefits</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td><strong>Labor</strong></td>
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<td></td>
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<tr>
<td>Control Center Operator</td>
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<tr>
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<tr>
<td><strong>Total Labor</strong></td>
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<tr>
<td><strong>Non-Labor</strong></td>
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<tr>
<td>Energy</td>
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<tr>
<td>Management &amp; Administration</td>
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<td><strong>Total Annual Operations Costs</strong></td>
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<td>$9,212,500</td>
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<table>
<thead>
<tr>
<th>Annual Maintenance Costs</th>
<th>Personnel</th>
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<tbody>
<tr>
<td><strong>Labor</strong></td>
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<tr>
<td>Vehicles</td>
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<tr>
<td>Electrical Systems</td>
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<tr>
<td>Guideway Inspection and Maintenance</td>
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<tr>
<td><strong>Total Labor</strong></td>
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<td>$1,710,000</td>
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<tr>
<td><strong>Non-Labor</strong></td>
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<tr>
<td>Spare Parts</td>
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<tr>
<td><strong>Total Annual Operations Costs</strong></td>
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<td>$3,510,000</td>
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</table>

**Total Annual O&M Cost is $12.7M**
Potential Benefits of “ECCO” Maglev at Ports of Los Angeles and Long Beach

- **Environmental Protection**
  - Clean, all-electric operation
  - Eliminates diesel exhaust from >1M truck trips per year
  - Secondary benefits from reducing local traffic congestion

- **Economical**
  - Automated transport reduces labor costs
  - Fuel savings are much greater than electricity costs

- **Energy efficient**
  - Passive maglev technology minimizes vehicle weight
  - Electric grid power will displace >1M gallons/year of fuel
  - Secondary benefits from reducing local traffic congestion
Other Potential Cargo Maglev Routes
Linear Induction Motor Rail (LIM™-Rail) Systems for Goods Movement
LIM-Rail™: Linear Induction Motor Rail

- **Goal:** Adapt linear motor technologies to existing rail
  - Take advantage of clean, efficient linear induction motor technology
  - Make use of existing rail infrastructure to minimize implementation time and costs

- **Solution:** LIM-Rail™ system for rail transport
  - Embed linear induction motor modules into rail bed
  - Propulsion achieved by inducing an electric current in aluminum plates mounted to the underside of vehicles

- **Advantages over other rail electrification methods**
  - No electrified third rails or overhead power lines – fewer safety issues and less intrusive
  - No motors or active power systems onboard vehicles – reduces weight and cost of vehicles
LIM-Rail™: Principles of Operation

- Rail component
  - Linear induction motors (LIMs) can propel objects using same principle used to spin rotors of AC induction motors
  - Built into hardened modules and fastened to railroad ties between rails, LIMs can propel rail vehicles along tracks

- Vehicle component
  - Reactive plates made of any conductive material (typically aluminum) can be used to propel vehicles
  - Reactive plates are mounted to undersides of vehicles
  - Moving magnetic fields generated by LIMs induce currents in reactive plates, which are then pulled along the LIM segment

- Principles are proven
  - Linear motors are used in several rail systems around the world
  - LIM-Rail™ reverses the usual method of linear motor operation, placing the linear motor in the track instead of on the vehicle
Illustration of LIM-Rail™ Concept

Al plate mounted under locomotive or rail car

SIDE VIEW

Linear motors embedded in railway

TOP VIEW

Block Switch

Inverter

Power Cable Conduit

Rail

GENERAL ATOMICS
Major Components Required for LIM-Rail™

- Inverter/Rectifier
- Block Switches
- Linear Motor Stators

(Photos of actual hardware from GA EMALS Program)
EMALS TEST SITE
LAKEHURST, NJ

150 kts

75 kts
Alternative LIM-Rail™ Operating Modes

Retrofitted Locomotives

- Fastest approach to achieving near term results
  - Fewer cars to be retrofitted
  - Minimum change to current rail operations
- Gives railroads greatest flexibility
  - Trains can operate on standard or LIM-Rail track
  - May eliminate need for “helper” locomotives to assist trains up hills
- Requires higher thrust motors in track (greater rail investment)
- Minimal improvement in throughput

Retrofitted Rail Cars

- Lower rail cost (less thrust required)
- Maximizes LIM-Rail benefits
  - Eliminates need for locomotives
  - Cargo cars can be dispatched independently – increasing efficiency and throughput
  - Automation can reduce operating costs
- Could take longer to achieve results
  - Requires investment in automated control
  - All rail cars must be retrofitted (vs. just locomotives)
- Requires greater railroad culture change

Both options reduce fuel use and emissions (vs. conventional diesel)
• Environmental Benefits
  ➢ Eliminates diesel exhaust from locomotives
  ➢ Eliminates engine noise

• Economic and Efficiency Benefits
  ➢ Electric energy cost is lower than equivalent fuel cost
  ➢ Widespread use can reduce dependency on fossil fuels

• Operational Benefits
  ➢ Makes use of existing rail and rail vehicle infrastructure
  ➢ Achieves electrification without third rails or overhead lines
  ➢ Can be used in conjunction with diesel locomotives
    • LIM-Rail™ can augment diesel power during periods of high power usage (e.g., hill-climbing) and can recapture energy
    • Diesel power can be used as a backup in case of power outages
Potential Sites for Initial LIM-Rail™ System

Port of Los Angeles/Long Beach

Alameda Corridor

Victorville/Inland Empire
LIM-Rail™: Suggested Next Steps

- **Engineering Feasibility Study (~6 months)**
  - Perform key trade studies
    - Linear motor size and packing density
    - Reactive plate design/use (e.g., locomotives vs. all cars)
    - Operational scenarios
  - Develop designs for preferred configuration(s)
  - Generate credible estimates of costs and benefits
  - Option: build subscale (~100 meter) proof-of-concept system

- **Full-Scale Demonstration System (~2 years)**
  - 1 mile conversion of existing rail
  - Installation of reactive plates on several locomotives and/or rail cars
  - Sequence of operational tests to validate system
Conclusions
Calculation of Maglev/LIM-Rail™ NOx Reduction vs. Conventional Rail

- Same operating assumptions (500 million ton-miles/year of traffic)
- NOx emissions (cleanest conventional locomotives)
  - 103 g NOx/gallon fuel*
  - 103 g NOx/gallon fuel x 1.25 million gal/year = 128.75M g NOx/year
  - 128.75M g NOx/year = 142 tons NOx/year
- NOx emissions (Maglev or LIM-Rail™)
  - 0.15 lb NOx/MWhr (2000 SCE power plant rule)
  - 0.15 lb NOx/MWhr x 13,300 MWhr/year = 1,995 lb NOx/year
  - 1,995 lb NOx/year = 1 ton NOx/year


NOx reduction of 99.3% or 141 tons/year
Calculation of Maglev/LIM-Rail™ Fuel Savings vs. Conventional Rail

• Operating assumptions
  • 10-mile route
  • 1 million cargo cars per year
  • 50 tons/car → 500 million ton-miles of traffic per year

• Diesel fuel cost (conventional locomotives)
  • 400 ton-miles/gallon fuel
  • 500 million ton-miles ÷ 400 ton-miles/gal = 1.25 million gal/year
  • 1.25 million gal/year x $2.50/gal = $3.13M/year diesel fuel cost

• Electricity cost (Maglev or LIM-Rail™)
  • 0.5 lb diesel/Hp-hr → 14 Hp-hr.gal → 10.6 kWhr/gal
  • 400 ton-miles/gal ÷ 10.6 kWhr/gal = 37.7 ton-miles/kWhr
  • 500 million ton-miles ÷ 37.7 ton-miles/kWhr = 13.3M kWhr
  • 13.3M kWhr x $0.085/kWhr = $1.13M/year electricity cost

$2 million/year in diesel fuel savings
Conclusions: Maglev

- Maglev is in many respects the “ultimate solution” to meeting future goods movement challenges
  - Pollution mitigation
  - Noise reduction
  - Congestion mitigation
  - Increased throughput

- Near term studies and demonstrations can validate these benefits and identify most cost-effective applications
Conclusions: LIM-Rail™

- Innovative combination of existing infrastructure with advanced technology
- Offers significant, near term environmental benefit by reducing diesel exhaust from locomotives and trucks whose cargo can be transferred to LIM-Rail™
- Widespread adoption could significantly reduce petroleum consumption and improve economics of rail transport
- Initial application to goods movement can be demonstrated within two years for less than $20M