Maglev and Linear Motors for Goods Movement

AQMD Container Movement Forum

26 January 2007

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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

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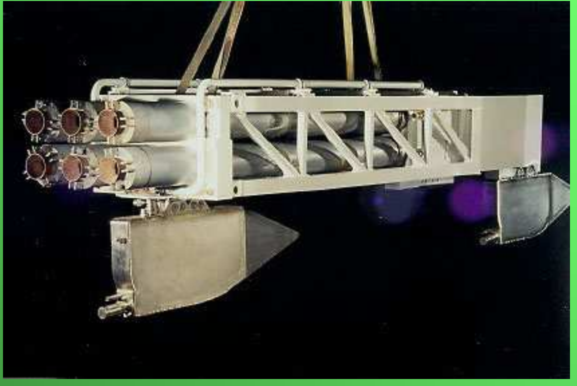
GA Electromagnetic Project Experience

FTA Urban Maglev

California-Nevada
High-Speed Maglev



Air Force Holloman
High-Speed Maglev

Navy Electromagnetic
Aircraft Launch System

General Atomics Maglev Activities

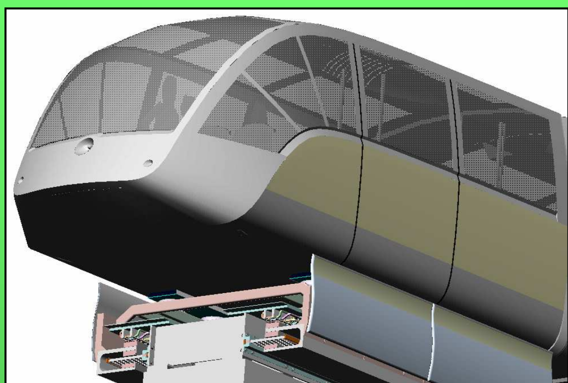
Transrapid system in Shanghai

- **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

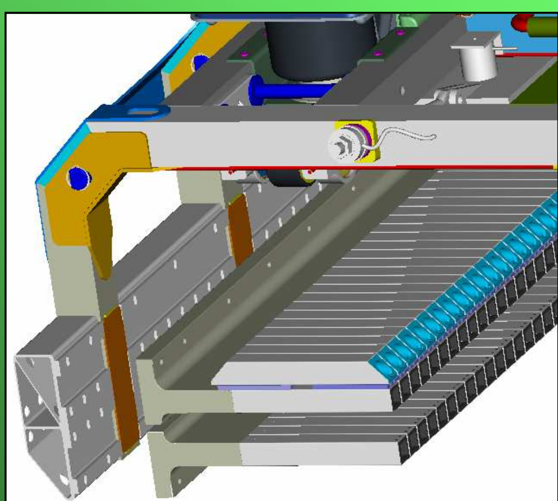
General Atomics "Urban Maglev" artist's concept

- **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

The General Atomics "ECCO" Study Team

THE PORT OF LOS ANGELES ©

GENERAL ATOMICS
Prime Contractor and
Maglev Systems

California State University
LONG BEACH

Mackin
Civil Engineering

hi
Chassis

Lawrence Livermore
National Laboratory
Magnetics Analysis

UNION SWITCH & SIGNAL
Communications & Signaling

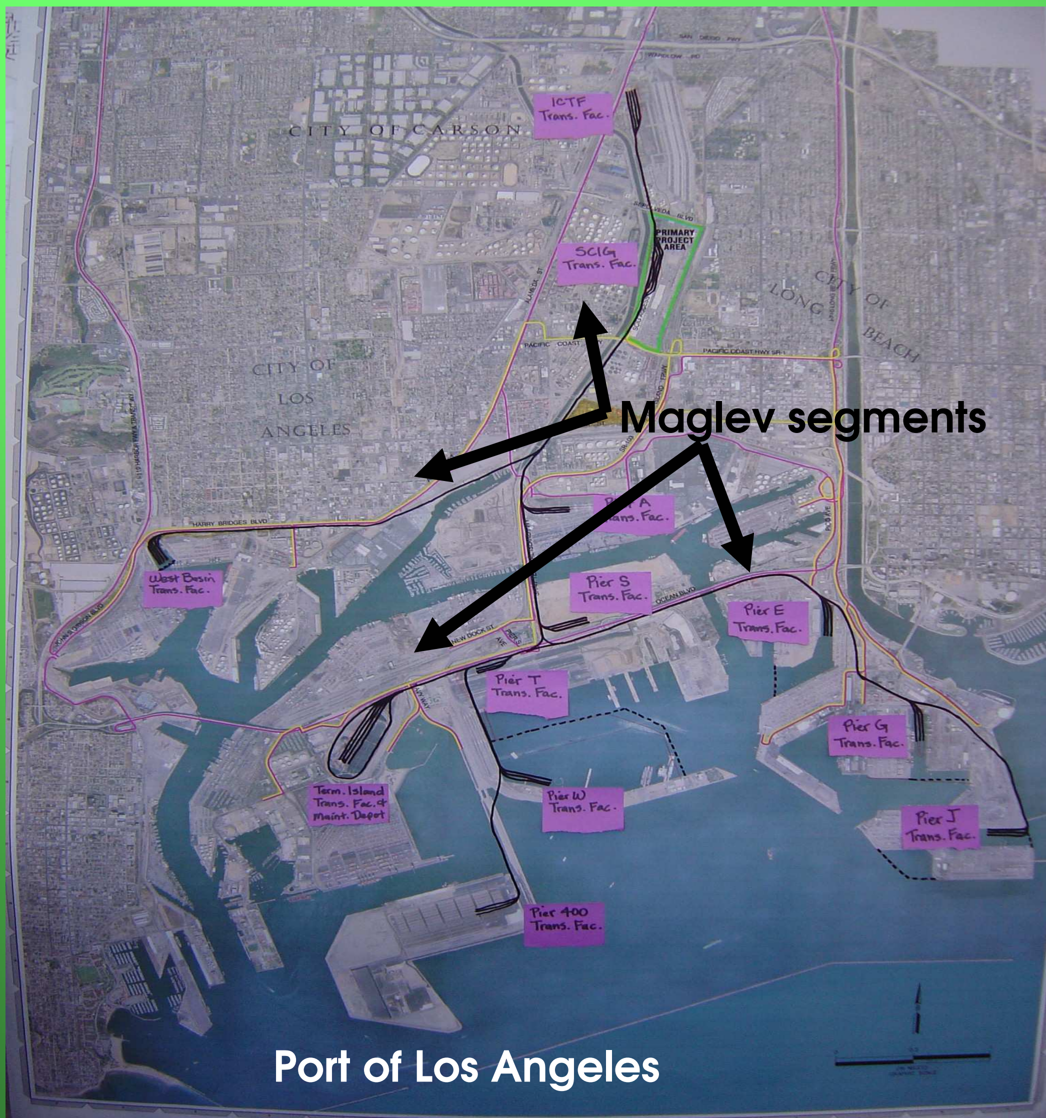
Port of LA ECCO Study Guidelines

• Container trips per day:	5,000 (2,500 per direction)
• Container size:	Up to 40’
• Container weight:	30,482 Kg (67,200 lbs)
• Operation hours:	24 hours

ECCO Operational Parameters

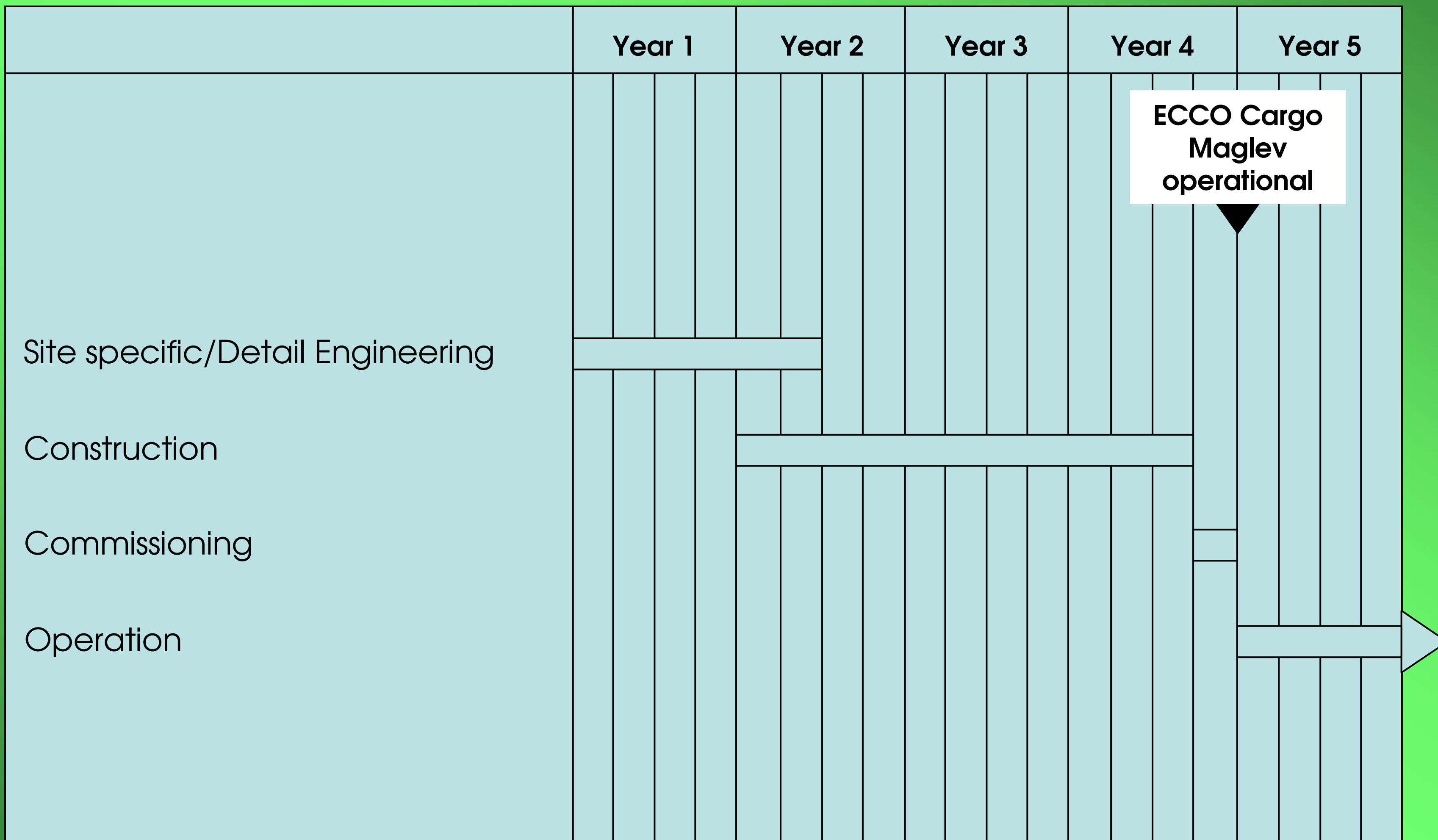
• Maximum Speed:	145 kmph (90 mph)
• Acceleration:	1.6 m/s^2
• Trip time (high-speed section):	3.5 min.
• Average speed:	~122 kmph (~80 mph)
• Headway:	20 seconds
• Maximum g loading:	
➢ Longitudinal, vertical, lateral (nominal):	0.16 g (1.6 m/s^2)
➢ Longitudinal (emergency):	0.36 g (3.6 m/s^2)
• External 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



ECCO Maglev Costs*

Maglev System Element	Cost/Mile ($)
Guideways and civil structures	10,000,000
Maglev track and propulsion components	20,500,000
Electrical energy supply equipment	15,000,000
TOTAL	**45,500,000**

(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

Annual Operations Costs	Personnel	Salary & Benefits	Cost
Labor			
Control Center Operator	10	$ 60,000	$ 600,000
Security	5	$ 40,000	$ 200,000
Total Labor			**$ 800,000**
Non-Labor			
Enengy			$ 8,212,500
Management & Administration			$ 200,000
Total Annual Operations Costs			**$ 9,212,500**

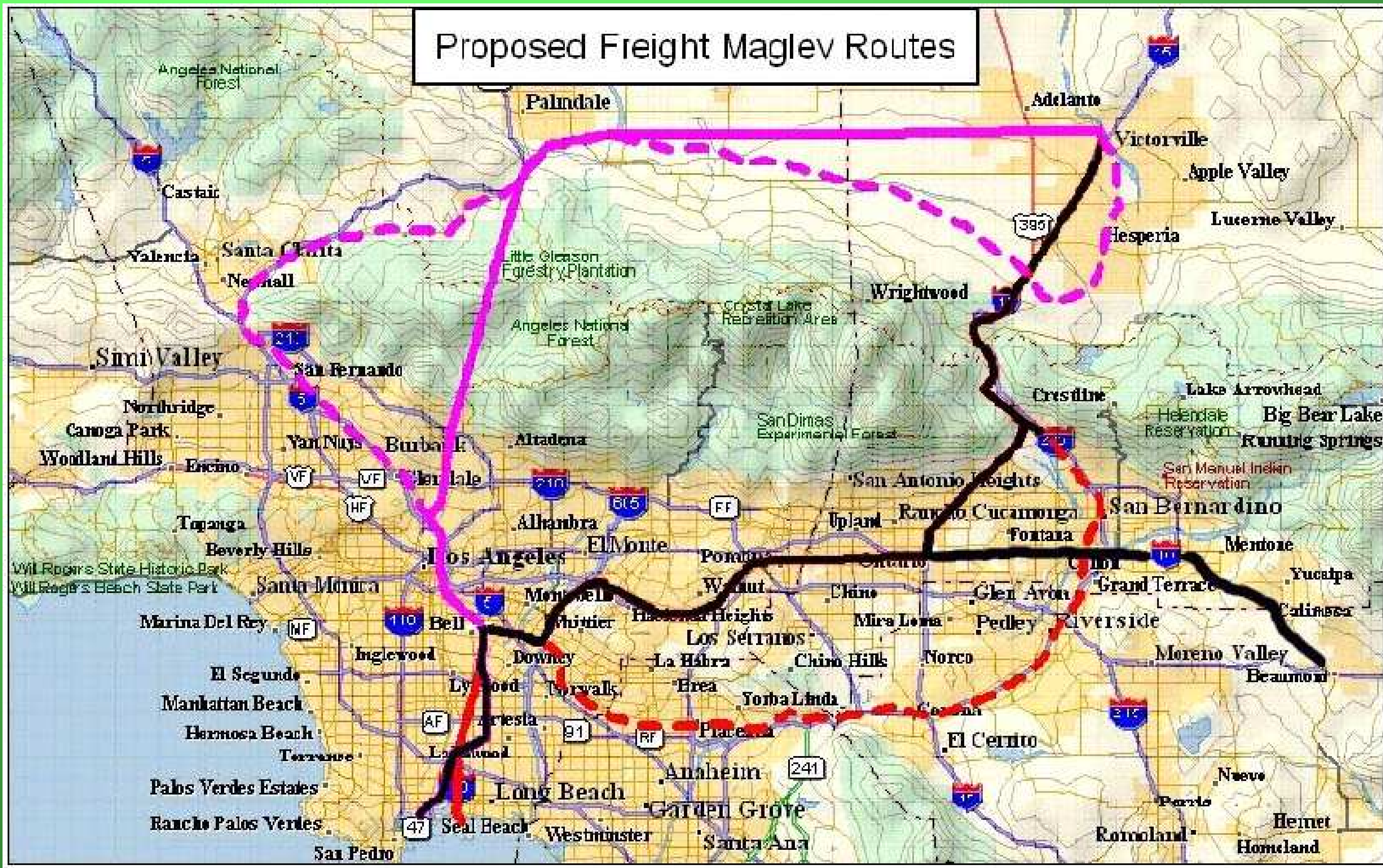
Annual Maintenance Costs	Personnel	Salary & Benefits	Cost
Labor			
Vehicles	6	$ 90,000	$ 540,000
Electrical Systems	8	$ 90,000	$ 720,000
Guideway Inspection and Maintenance	5	$ 90,000	$ 450,000
Total Labor			**$ 1,710,000**
Non-Labor			
Spare Parts			$ 1,800,000
Total Annual Operations Costs			**$ 3,510,000**

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



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

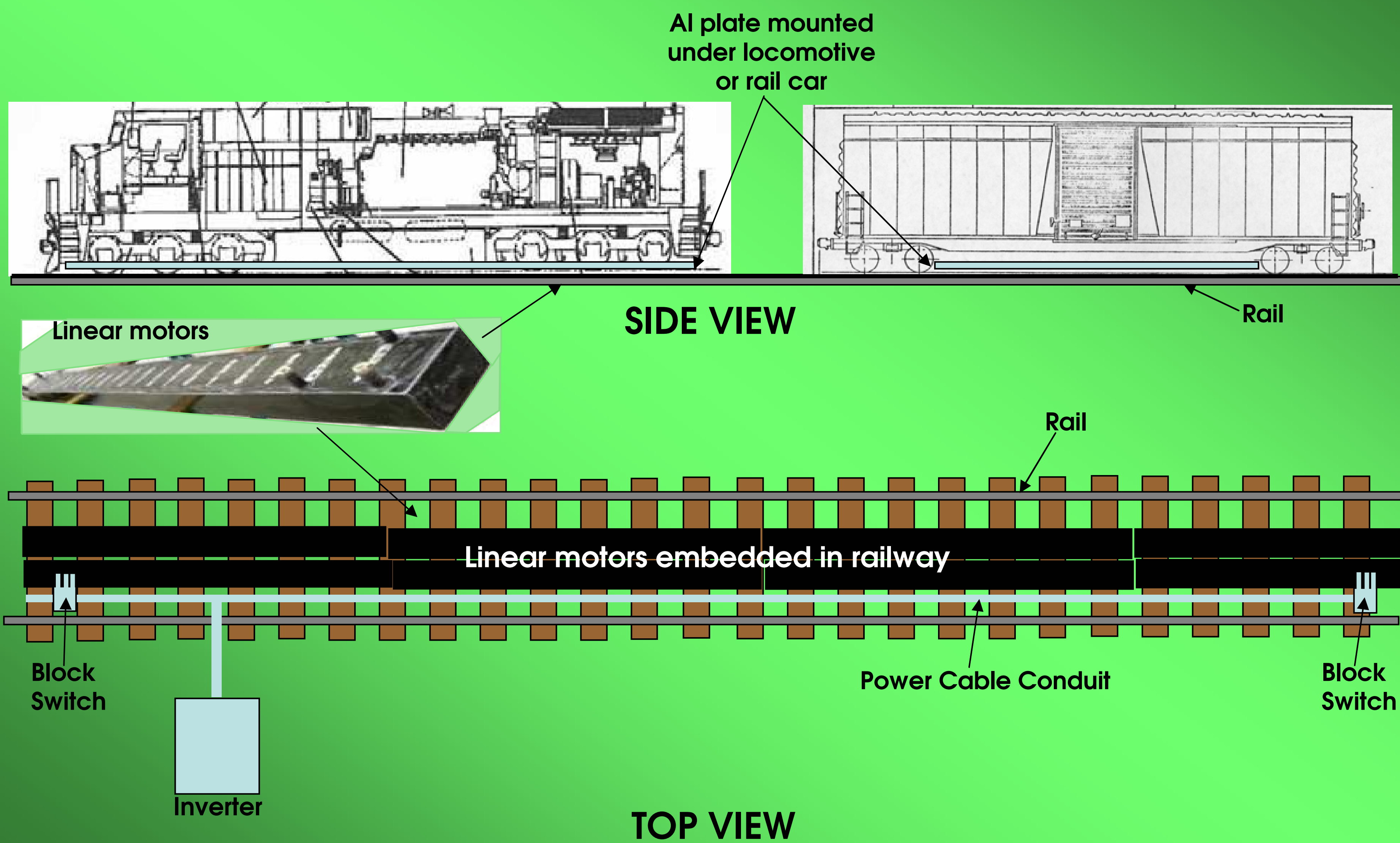
LIM-Rail™: Linear Induction Motor Rail

- 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



Major Components Required for LIM-Rail™

Inverter/Rectifier

Block Switches

(Photos of actual hardware from GA EMALS Program)

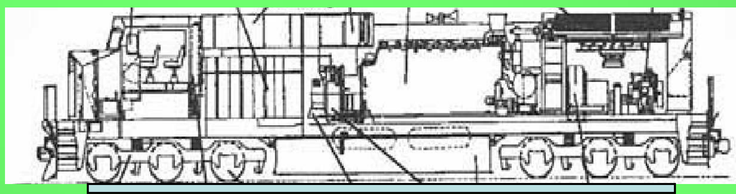
Linear Motor Stators

EMALS TEST SITE
LAKEHURST, NJ

150 kts

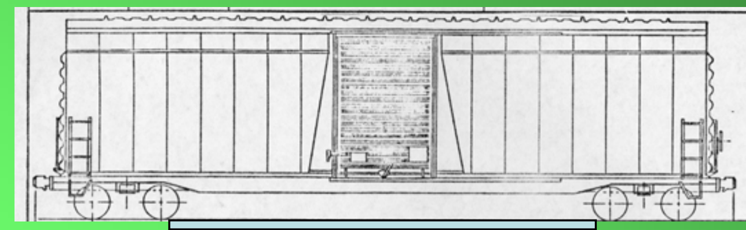
75 kts

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)

LIM-Rail™ Benefits for Goods Movement

- 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

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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 (*<u>cleanest</u>* 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**

** Tier 2 EPA standard for 2002-04 line haul locomotives; source: EPA "Technical Highlights, Emission Factors for Locomotives" EPA420-F-97-051, December 1997*

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 = <u>$3.13M/year diesel fuel cost</u>
- 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 = <u>$1.13M/year electricity cost</u>

$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

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