# Maglev and Linear Motors for Southern California Transportation

**Presentation to SCAG Maglev Task Force**

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# Presentation Topics

- Background: Application of Electromagnetic Technology to Transportation
- Transportation Systems Using GA Passive Maglev Technology
- Linear Induction Motor Rail ("LIM-Rail™") Systems
- Conclusions

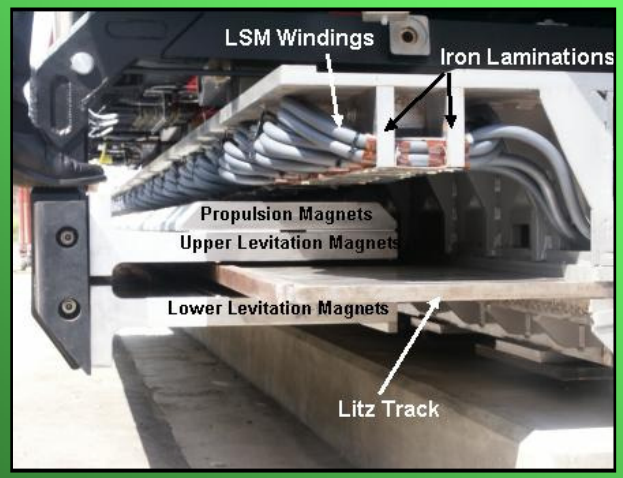
# Background: Application of Electromagnetic Technology to Transportation

# Critical Transportation Issues Facing CA

- **Environmental impact, especially emissions of NOx and diesel particulate matter**
- **Other social and economic impacts**
  - **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 Transportation Applications

- **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

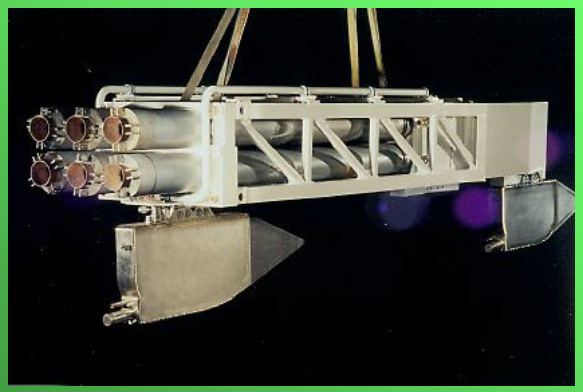
**Transportation**

- Maglev Systems
- Streetcar Refurbishment
- Mining Truck Drives
- Track Refurbishment

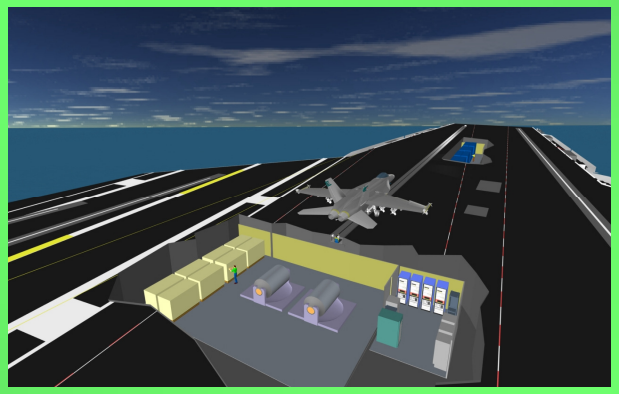
# GA Electromagnetic Project Experience

FTA Urban Maglev

California-Nevada
High-Speed Maglev



Air Force Holloman
High-Speed Maglev



Navy Electromagnetic
Aircraft Launch System

# General Atomics Maglev Activities

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

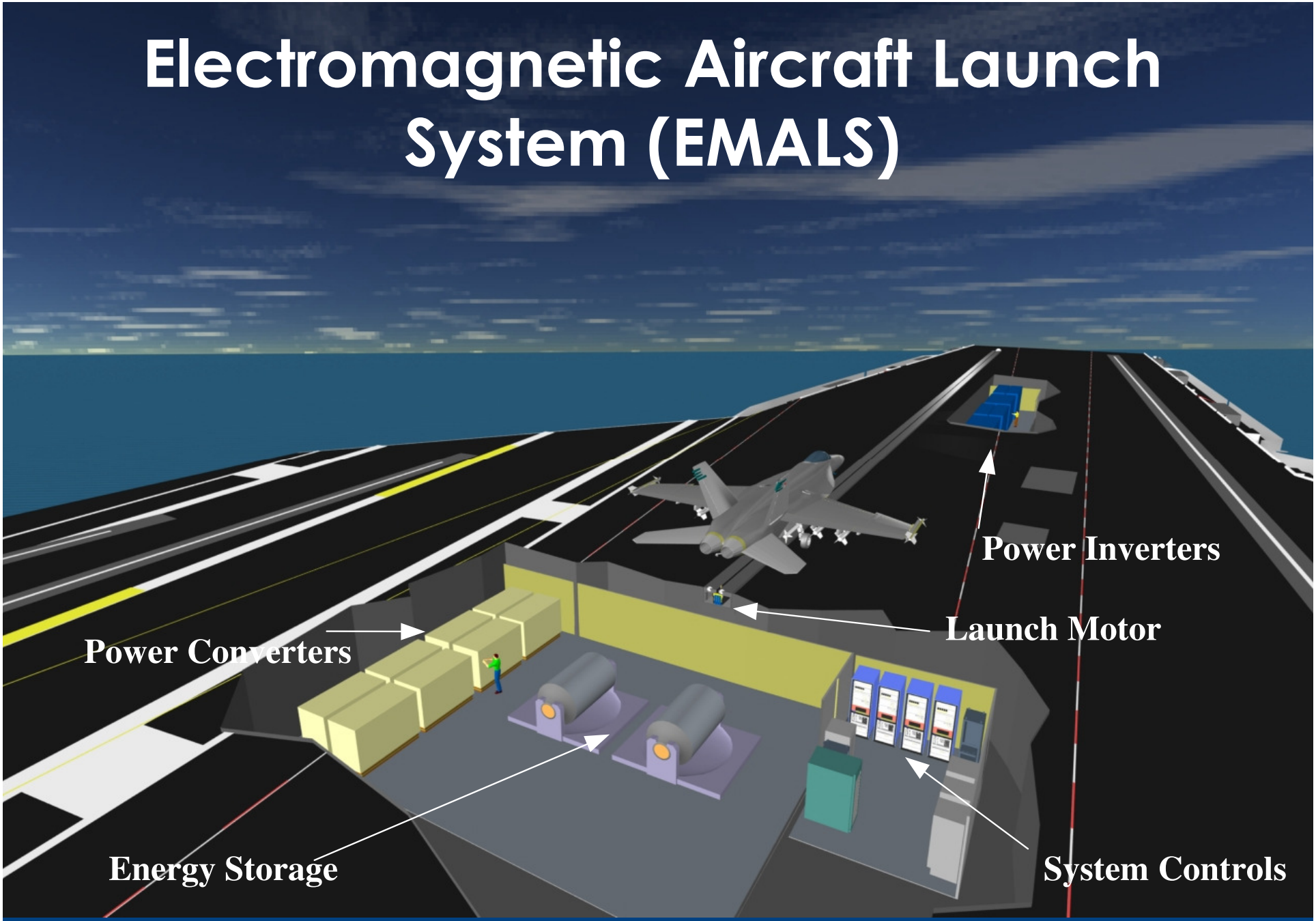
General Atomics "Urban Maglev" artist's concept

- **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*

# General Atomics Maglev Test Track

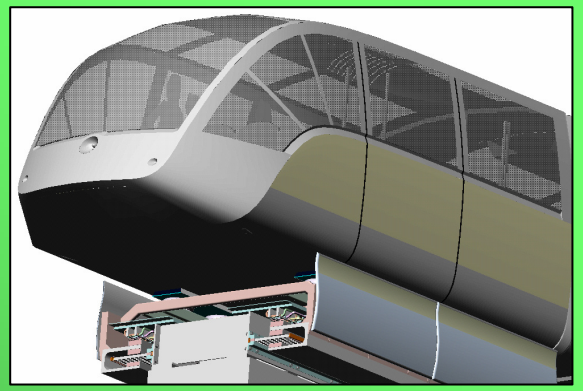
- **San Diego, CA**
  - Completed in September 2004
  - 400 ft. long
  - Highly instrumented test vehicle to validate ride quality and system performance
  - ***Only full-scale, functional maglev system in U.S.***

# Electromagnetic Aircraft Launch System (EMALS)

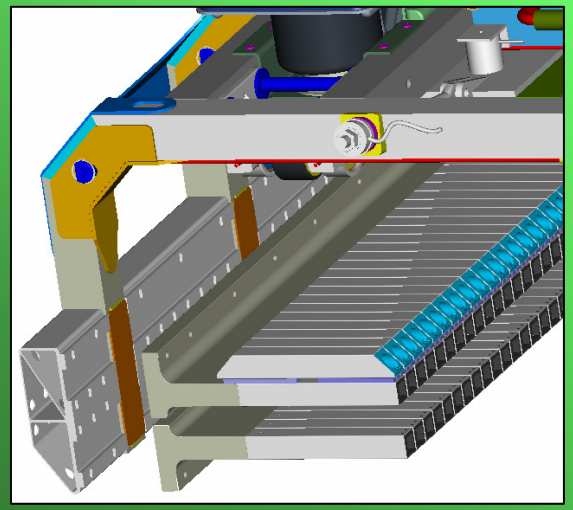


# Transportation Systems Using GA Passive Maglev Technology

# GA Passive Maglev Technology



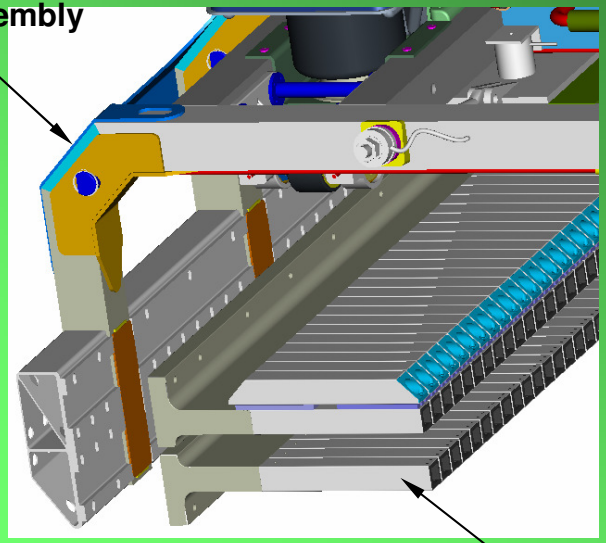
- **No active power system on vehicle – only permanent magnets**
  - Mounted to vehicle undercarriage
  - React against linear synchronous motor contained within guideway

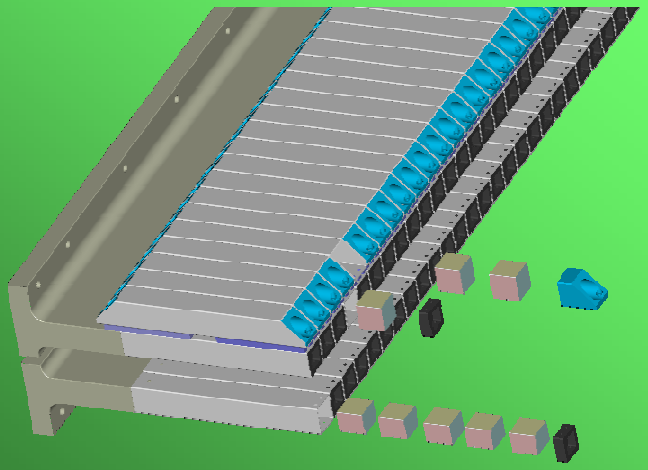


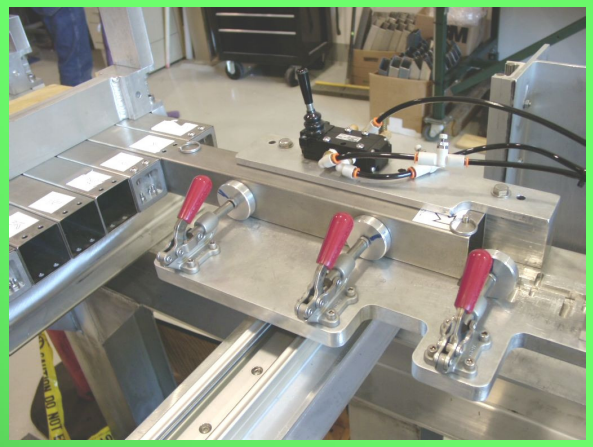
- **"Halbach Array" of magnets**
  - Upper row provides forward propulsion
  - Lower rows induce currents in guideway, providing levitation
  - Configuration enhances magnetic field strength and efficiency, without exceeding safety thresholds

# GA Passive Maglev: Magnet Modules

- **Magnet blocks**
  - Neodymium-Iron-Boron (NdFeB)
  - Subdivided into sub-assemblies
  - Loaded into the magnet modules
- **Chassis Assembly**
  - Magnet modules are then mounted to the chassis supports

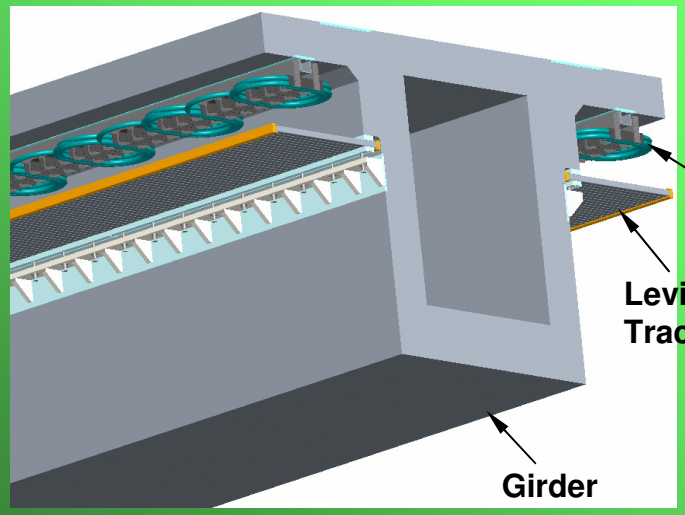


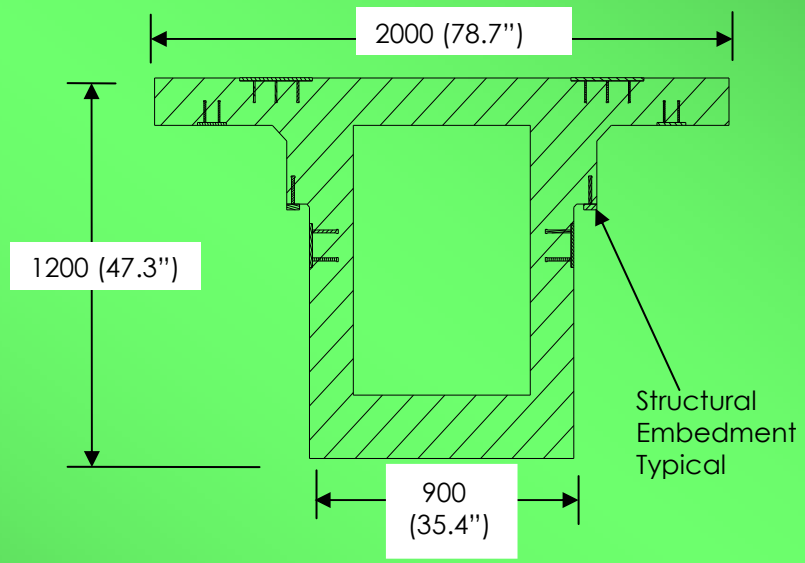





# GA Passive Maglev: Guideway Modules

- **Guideway Modules**
  - Linear Synchronous Motor
  - Levitation Track
  - High Speed Turns (144 km/hr, 90 mph)
    - 800 meter min. turn radius
    - $11.5^0$ Cant Angle
  - Future Concept: Hybrid Guideway Girder
- **Steel Fiber Reinforce Concrete (SFRC)**
    - In early stages of development



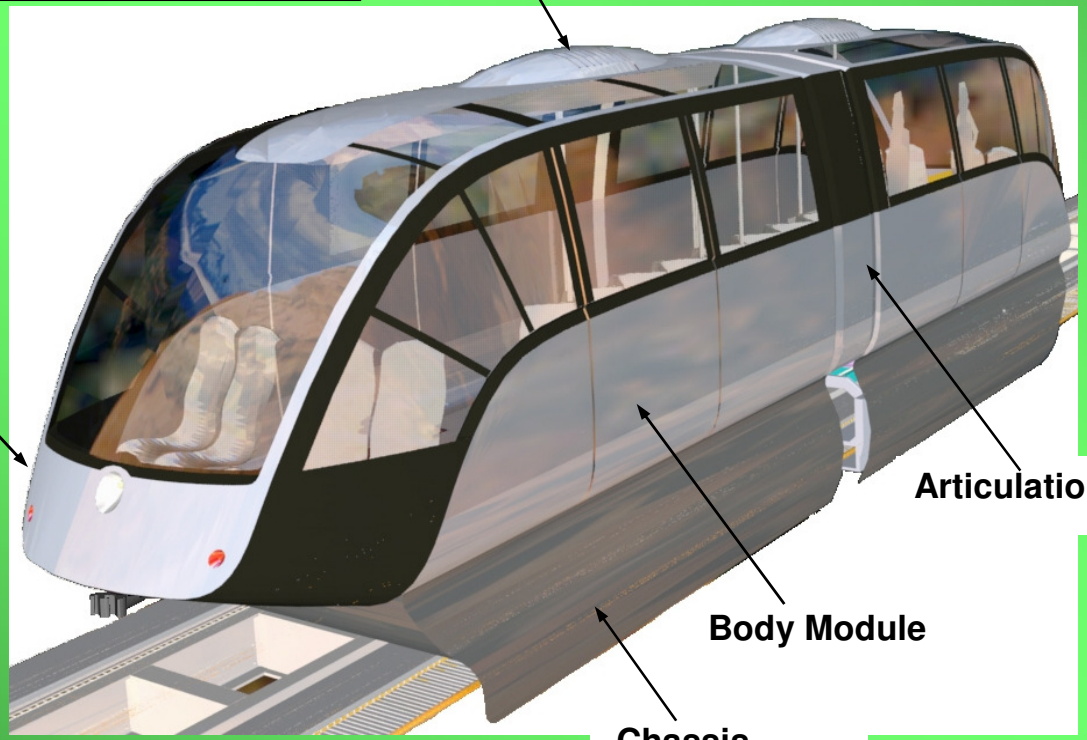
# GA Passive Maglev: Unique Benefits of Technology

- **Lighter, less expensive vehicle**
  - No active onboard power systems – just permanent magnets
  - Especially beneficial for high throughput applications, e.g. cargo movement
- **Lighter, less expensive guideway**
  - Vehicle weight that must be supported is lower
  - Large air gap reduces complexity of guideway manufacturing
  - Especially beneficial in urban areas where large guideway supports would be difficult to site or intrusive
- **No high power pickup system ("third rail") required**

*Particularly attractive for passenger and goods movement in congested metropolitan areas*

# GA Urban Maglev Vehicle Concept

- 2 Chassis Car Length – 13 m
- Car Width – 2.6 m
- Car Height – 3 m



# GA Urban Maglev Activities

- California University of Pennsylvania
  - Funded by the FTA and Pennsylvania DOT since ~2000
  - Preliminary environmental and feasibility studies completed
  - Ultimate goal is to secure funding for a 4.5 mile system
- Other applications
  - Proposal to Disneyland in 2004
  - Discussions with Colorado stakeholders regarding I-70 corridor linking Denver and Aspen ski areas (past several years)
  - Also considered: LAX-Ontario airport connector, UCSD campus shuttle
- Technology development activities are continuing

# 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

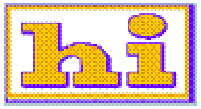
* ECCO = Electric Cargo COnveyor

# The General Atomics "ECCO" Study Team

**Prime Contractor and Maglev Systems**

Mackin

**Civil Engineering**




**Chassis**

**Magnetics Analysis**

**Communications & Signaling**

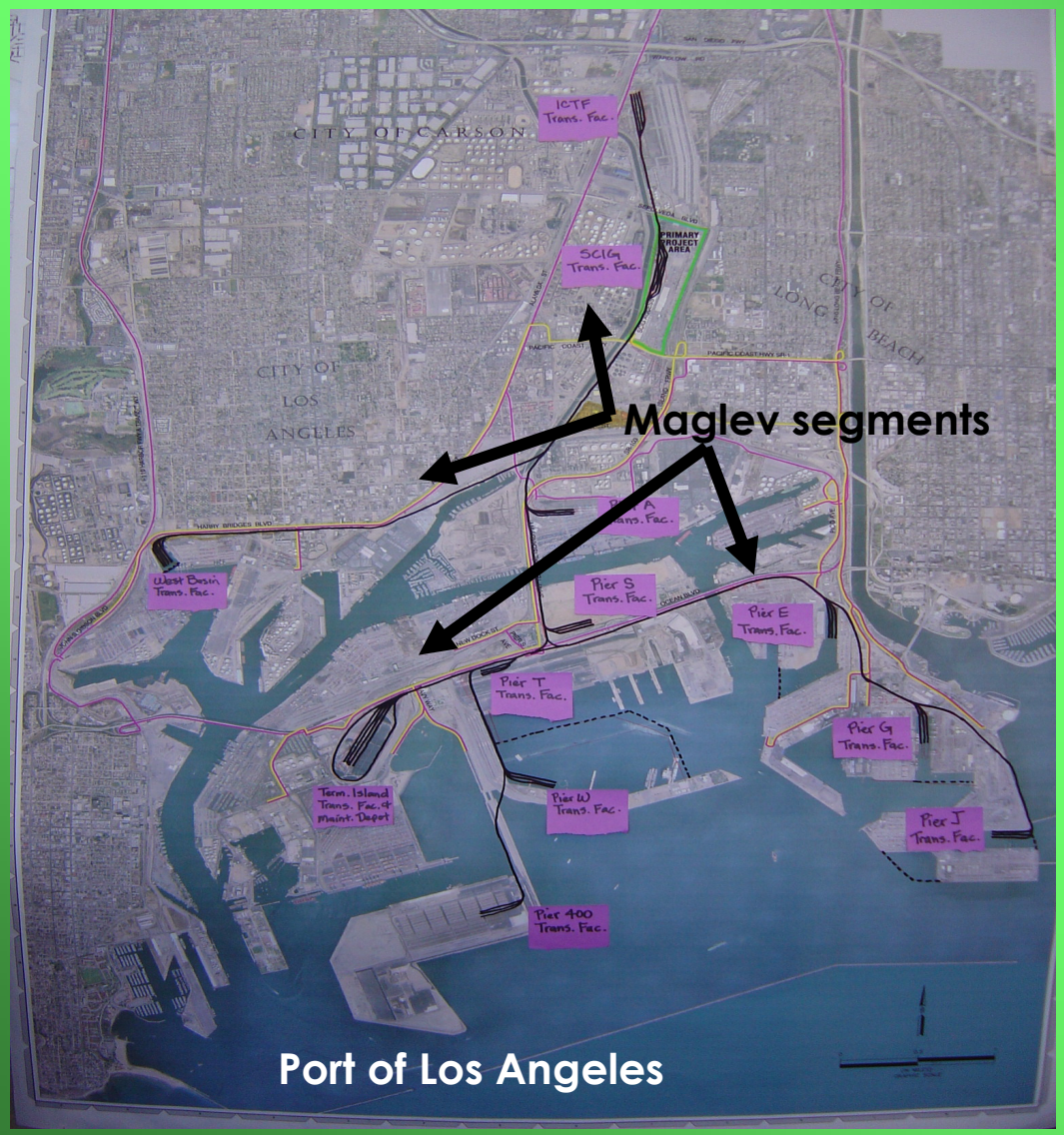
# Port of LA ECCO Study Guidelines

- 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

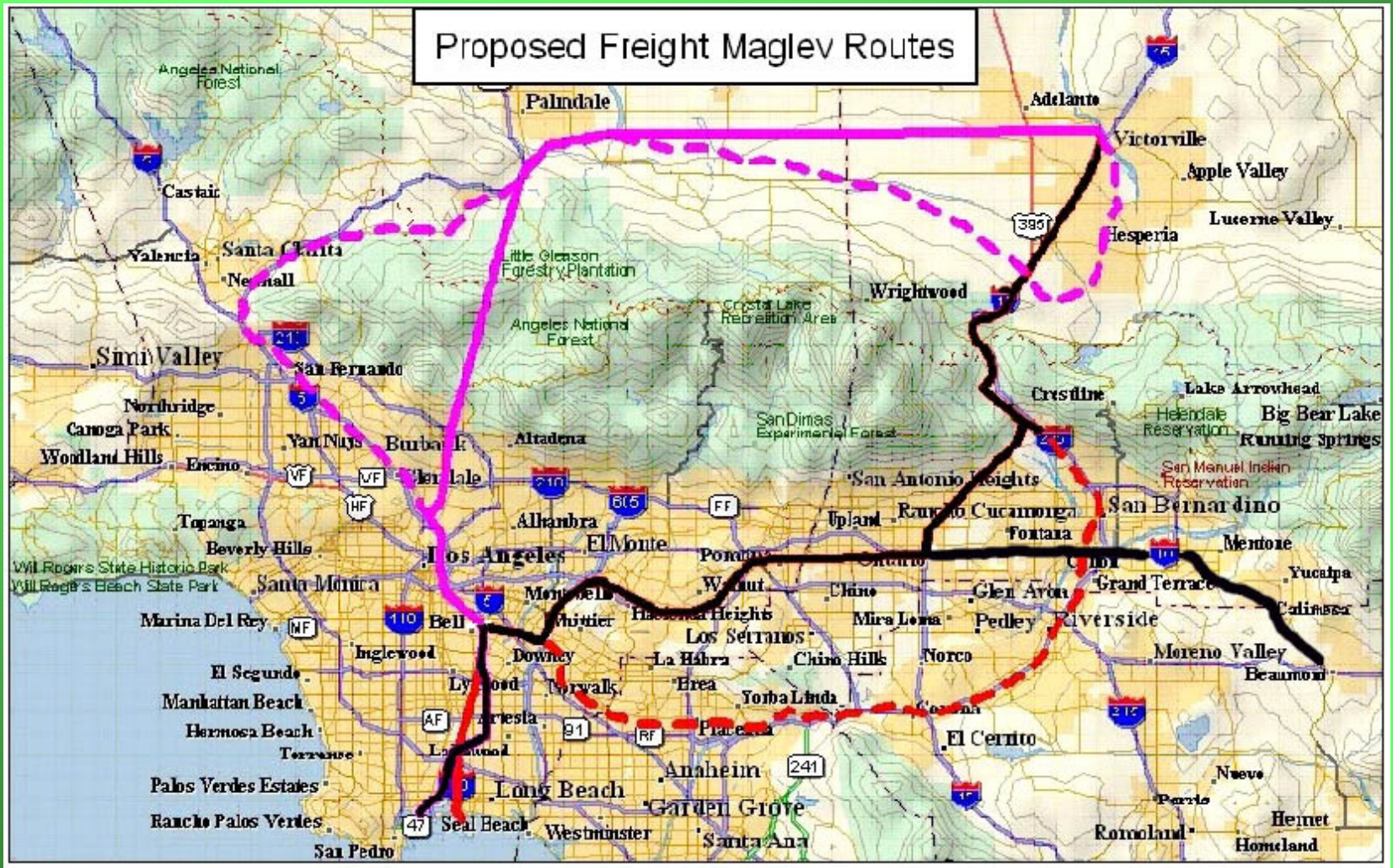
- Maximum Speed: 145 kmph (90 mph)
- Acceleration: 1.6 $m/s^2$
- Trip time (high-speed section): 3.5 min.
- Average speed: ~122 kmph (~80 mph)
- Headway: 20 seconds
- Maximum g loading:
  - Longitudinal, vertical, lateral (nominal): 0.16 g (1.6 $m/s^2$)
  - Longitudinal (emergency): 0.36 g (3.6 $m/s^2$)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

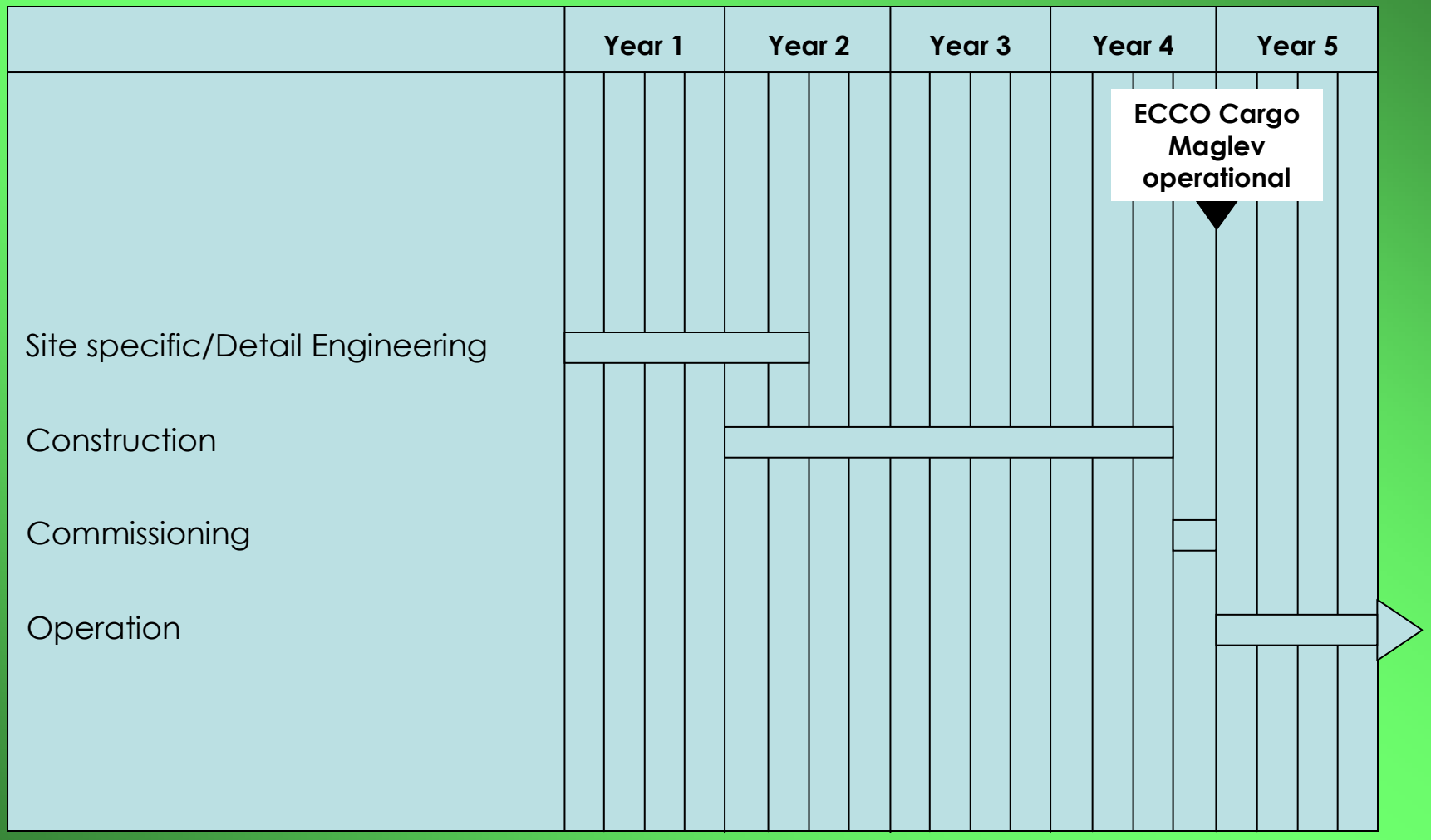
# Other Potential Cargo Maglev Routes






GENERAL ATOMICS

# ECCO Development Schedule






GENERAL ATOMICS

# Estimated 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

# Linear Induction Motor Rail (LIM™-Rail) Systems

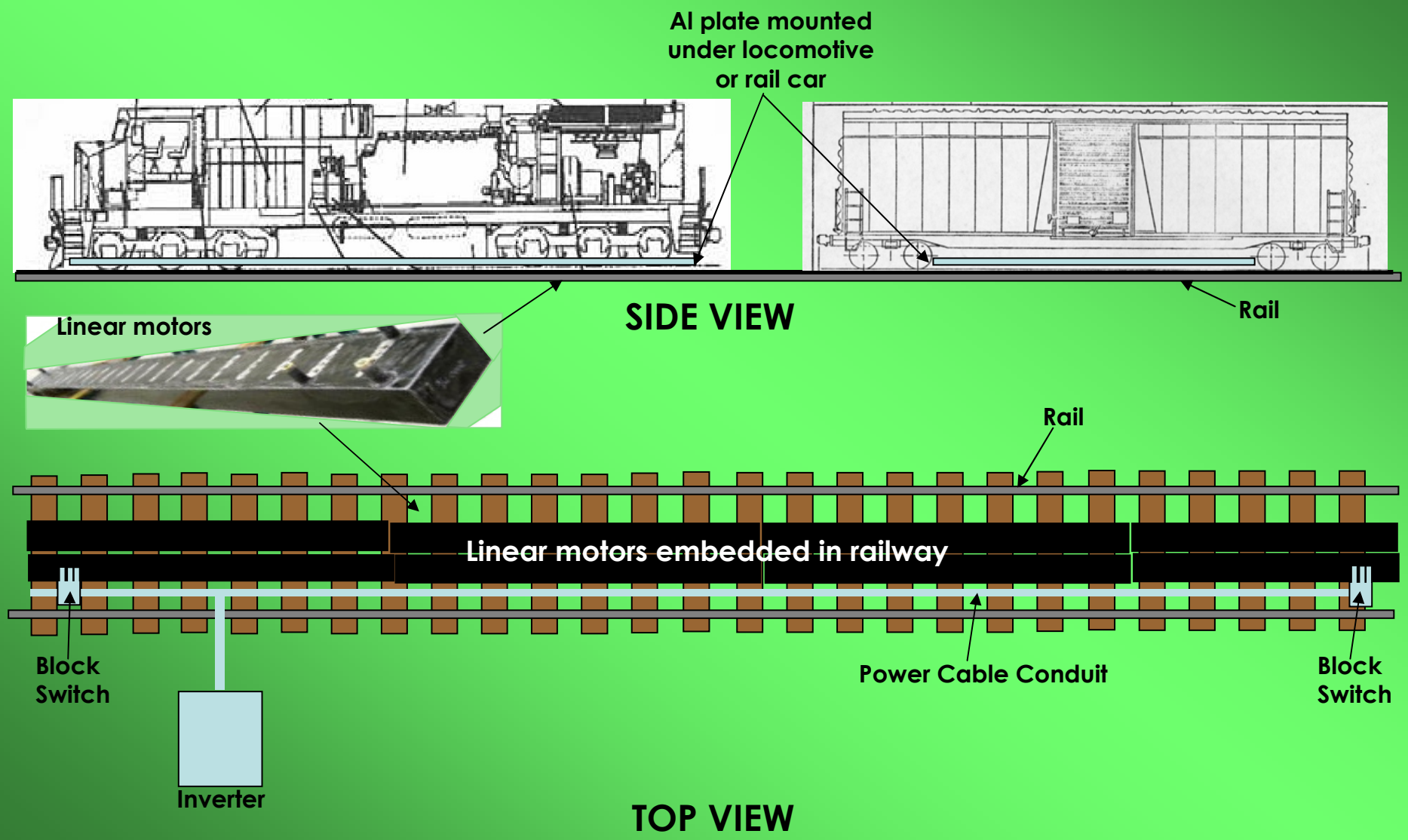
# LIM-Rail™: Linear Induction Motor Rail

- 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






GENERAL ATOMICS

# Major Components Required for LIM-Rail™

Inverter/Rectifier

Block Switches

(Photos of actual hardware from GA EMALS Program)

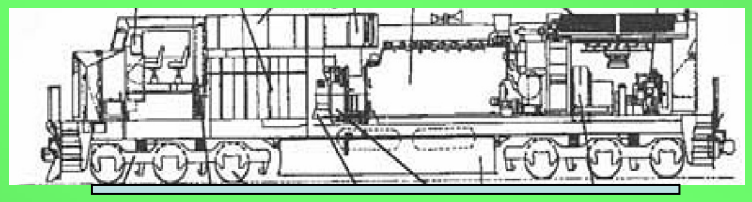
Linear Motor Stators

# EMALS TEST SITE
# LAKEHURST, NJ

150 kts

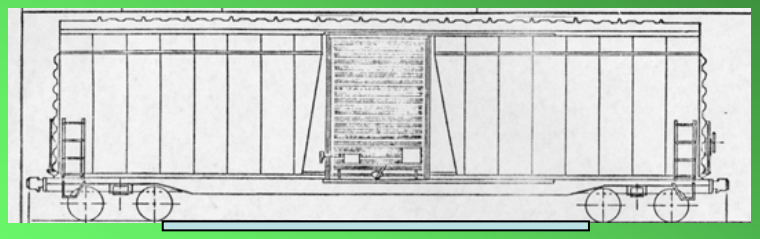
75 kts

# 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)***

# Potential LIM-Rail™ Benefits

- **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 LIM-Rail™ Applications

- System-wide Applications
  - As an alternative to standard diesel passenger or freight rail systems, eliminates exhaust emissions and saves fuel
  - As an alternative to conventional electrified rail systems, eliminates overhead power lines and electrified third rails
- Specialized Applications
  - Install on segments of track (passenger or freight) near populated areas to reduce emissions and noise
  - Install in vicinity of passenger commuter rail stations to reduce passenger exposure to diesel exhaust when trains accelerate out of stations
  - Install on grades to assist diesel trains in climbing hills and to recapture energy while descending
  - Install into sections of electrified rail lines where overhead lines or third rails present difficulties (e.g., at intersections or grade crossings)

# Possible LIM-Rail™ Uses in Southern CA

**GOODS MOVEMENT**

Port of Los Angeles/ Long Beach

Alameda Corridor

**PASSENGER RAIL**

Light Rail: Eliminate Overhead Lines

Metrolink: Mitigate Exhaust, Noise

# 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**

** 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 transportation 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
- As an alternative to conventional electrified rail systems, can eliminate overhead power lines and electrified third rails
- Target cost of $10M/mile is competitive with other means of rail electrification