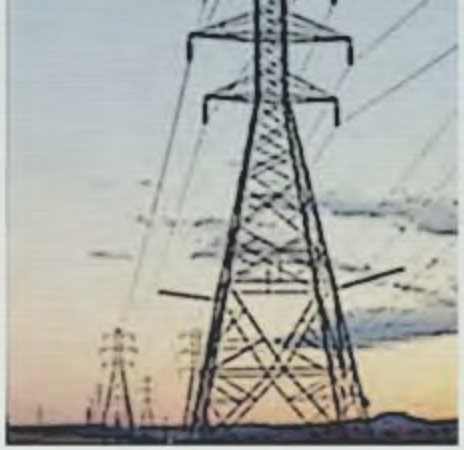




Maglev Energy Storage and The Grid

Presented by

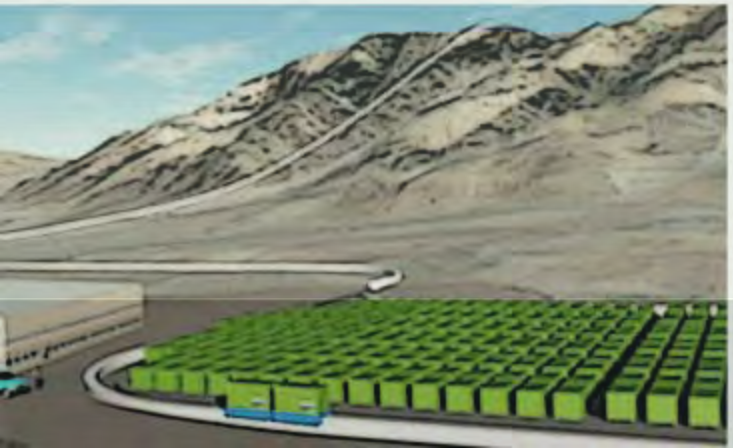
Dr. James Powell, Dr. Gordon Danby and Robert Coullahan

GE Emerging Energy Storage Technologies Event

GE Global Research Center

One Research Circle, Niskayuna, NY 12309-1027

7 December 2010

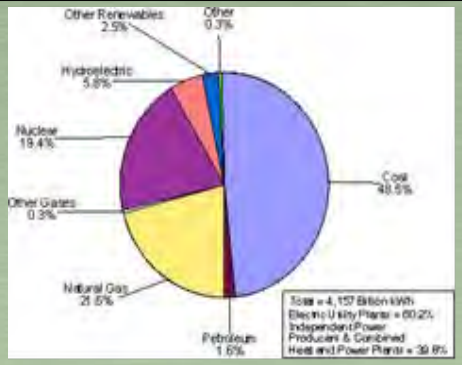


Overview

- **Wind and Solar Power Sources Require Low Cost, Large Scale, Bulk Energy Storage to Be Major Sustainable Energy Supply for the US and the World**
  - **Their Capacity Factors are Low (30% or Less)**
  - **Outputs Are Highly Variable & Often Do Not Match Demand**
- **Present Energy Storage Technologies Not Suitable**
- **Pumped Hydro, the Main Technology, Has Environmental, Efficiency, and siting Problems**
  - **Low Output/Input Efficiency, 60 to 70%**
  - **Limited Storage Capability – Only 2% of US Generation Capacity**
  - **Compressed Air Storage Has Similar Problems**
- **Dynamic Storage Systems (Flywheel, Batteries, etc) Are Very Small-Scale and Not Suitable for Bulk Storage –Potential for Grid Stabilization**
- **Maglev Energy Storage Very Promising New Technology For Large Scale Bulk Storage**
  - **Moves Mass Uphill to Store Energy; Downhill to Return Energy to Grid**
  - **Very High Storage Efficiency > 90%**
  - **Low Storage Cost, ~ 2 cents/KWH**

US Electrical Generation and Storage Systems

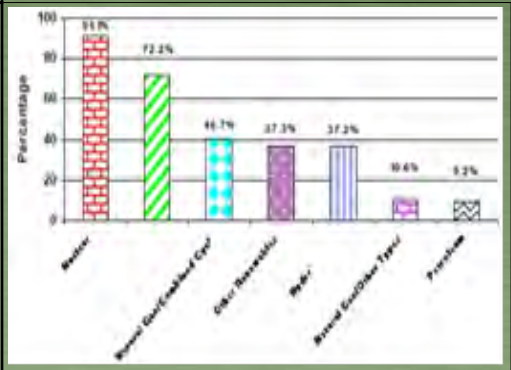
US Electrical Generation By Source



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

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

Average Capacity Factor By Source



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

2007 California Power Costs

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

US Generation = 1,000,000 MW

Average Power Cost= 97$/MWH

Storage Type	Capacity (MW)	Storage Cost ($/MWH)
Pumped Hydro	22,000 (US)	50-100
Compressed Air	400 (World)	N/A
Batteries	270 (World)	70-860

Flywheels, Hydrogen, SMES, etc are Negligible

The MAPS (MAglev Power System) Concept

How Does MAPS Store/Deliver Power?

Storage: Maglev Vehicles Move Mass Uphill

- Motor Mode
- 100 Ton Concrete Blocks
- 3000 Ft Lift = 250 KWH

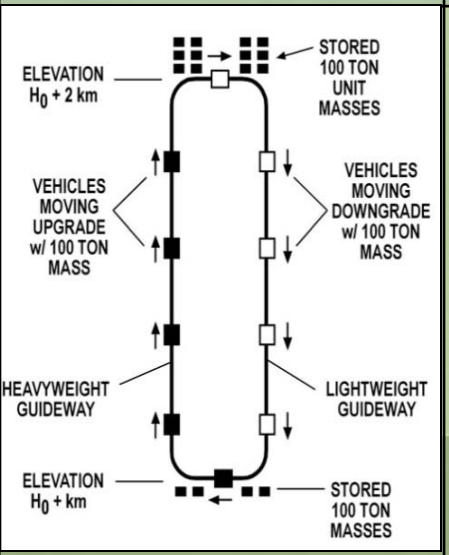
Delivery: Maglev Vehicles Move Mass Downhill

- Generator Mode
- Output/Input Efficiency > 90%

What Are MAPS Applications?

- Meets Power Demand Peaks
- Stores Power From
  - Wind & Solar Sources
  - Baseload Coal & Nuclear Plants
- Eliminates Natural Gas Peaking Plants
- Stabilizes Grid Against Accidents & Sabotage

MAPS, Energy Storage Mode



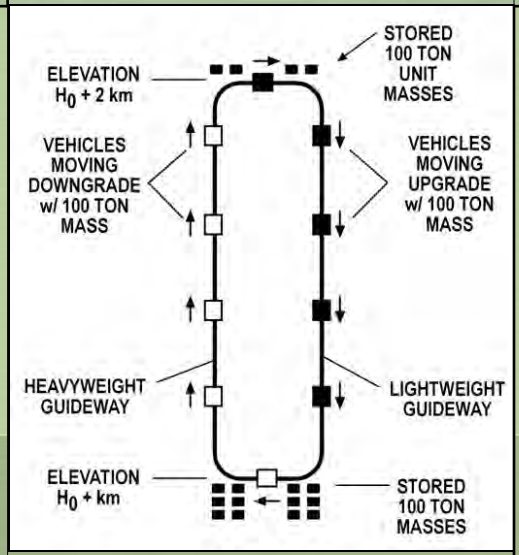
Individual Vehicle Can:

- Make 20 Round Trips/Hour

(Site Dependent)

- Store 40 MWH in 8 Hour Period
- Operate @ 30 MW Power Level

MAPS, Power Delivery Mode

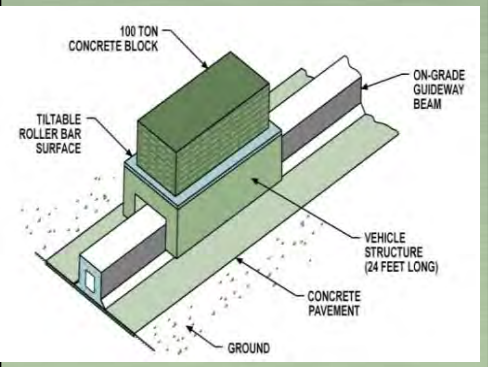


Multiple Vehicles Can:

- Operate on Guideway at Same Time
- Operate at Total Input/Output Power of 100's of MW
- Stores 1000's of MWH

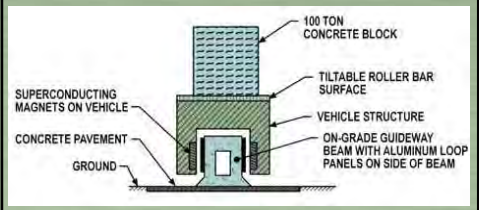
The MAPS Concept (continued)

Isometric View of Loaded MAPS Vehicle on Guideway



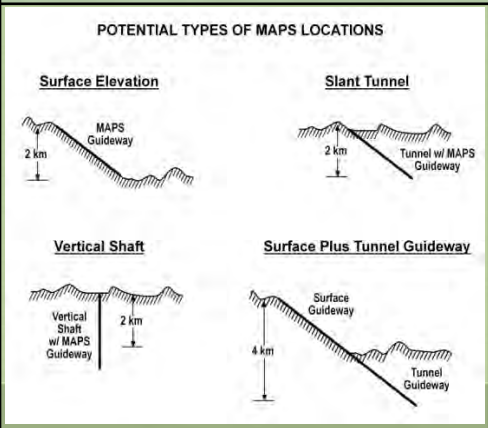
- Concrete Block Sits On Flat Sled
- Block Unloads/Loads Using Roller Bars
- Guideway Beams Cast in Place or Trucked to Site

Cross Section View of Loaded MAPS Vehicle



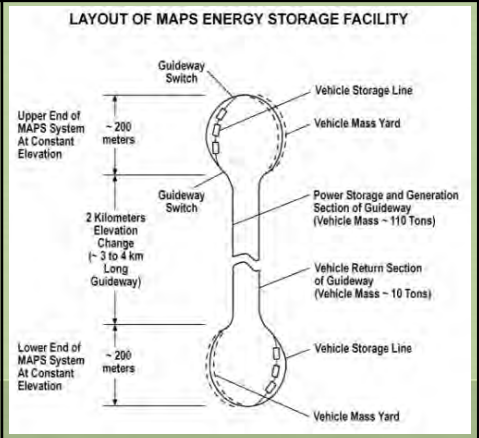
- Blocks Go To & From Storage Yard
- Roller Bar Transport System in Yard
- Vehicles Always Stably Levitated

Potential Types of MAPS Locations



- Wide Range of MAPS Sites
- Guideway on Grade in Hilly Terrain
- On Floor of Tunnel in Flat Terrain
- On Walls of Vertical Shaft in Flat Terrain

Layout of MAPS Energy Storage Facility



- 20 Acre Yard Stores 4,000 Blocks
- 1000 MWH (3000 feet Rise)
- 2000 MWH (6000 feet Rise)
- 30 MW Operating Power
- Non-Operating Vehicles I Quickly Accessible Siding

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 M$/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 (M$)	Amortized Capital Cost ($/MWH)	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 Power (purchased at 8 cents/kwh)	8.0
Concrete Blocks	20	1.8		
Handling Equipment	10	0.9		
Total	152	12.8		$16.1/MWH
		(1.3Cents/KWH)		(1.6Cents/KWH)
Total Cost/MWH = 12.8 + 16.1 =$28.9/MWH = 3 Cents/KWH for Illustrative MAPS System				

MAPS Market in US and World

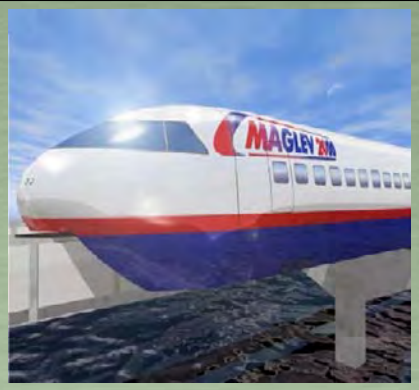
	US (Million MWH)	World (Million MWH)	
Parameter	2008	2008	2035 (EIA Projection)
Total Electric Generation	4,157	18,800	35,200
Coal	1,996	8,000	15,000
Natural Gas	883	4,000	7,500
Nuclear	806	2,600	3,600
Hydro	255	3,000	5,400
Wind	55	340	1,500
Solar	0.9	5	180
Potential Market for MAPS (Natural Gas+Wind+Solar)	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

Status of Superconducting Maglev and MAPS

1st Gen. Superconducting Maglev Transport

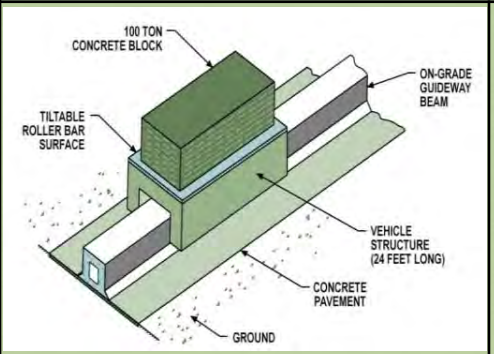
- Passengers Only
- 361 mph Speed Record
- Plan 300 mile Tokyo to Osaka Line
- 100,000 Passengers Daily

2nd Gen. Superconducting Maglev Transport



- Passengers, Autos, Highway Trucks & Freight
- Privately Financed
- Pay Back in 5 Years
- 28,800 Mile National Maglev Network
- Serves 232 Million Americans

Superconducting MAPS Energy Storage



- Simpler Technology
- On Grade Guideway
- Simple Sled Vehicles
- Iron Guideway Plates Increase Lifting
- 100 Ton Lifting Power, compared to 50 Ton for Highway Trucks

Next Steps for MAPS

- Test High Temperature SC Quadrupoles
- Demonstrate Sled With 100 Ton Lift Capability
- Demonstrate Roller Unloading/Loading System
- Test Magnetic Propulsion

Fabrication and Testing of Superconducting Maglev Hardware Relevant to MAPS

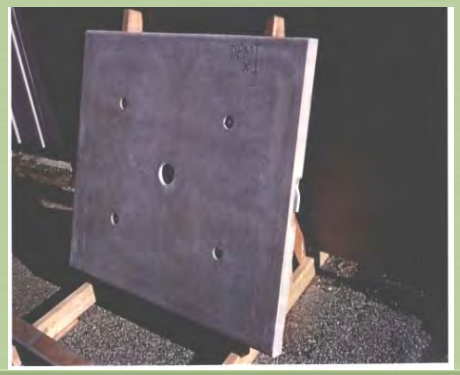
Superconducting (SC) Magnets

- SC NbTi Loops
- 600,000 Amp Turns
- Liquid (4K) Helium Cooled
- New High Temperature SC Replace NbTi

Aluminum (Al) Guideway Loop Panels

- 3 Al Loops Provide Lift, Stability & Magnetic Propulsion
- Mounted On Sides of Monorail or on Flat Surface Underneath Vehicle

Guideway Loops Encased in Polymer Concrete



- Al Loops Encased in Polymer Concrete Panel
- Polymer Concrete 4 Times Stronger
- Non-Degradable
- Immune to Freeze-Thaw Cycling

Guideway Beam

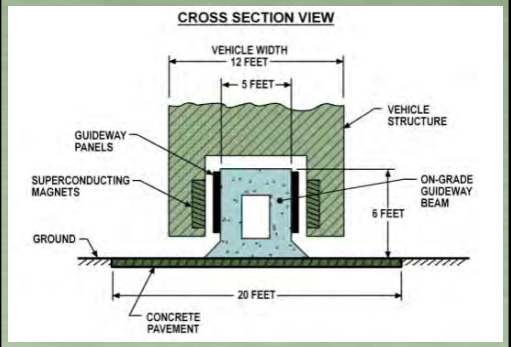
- 72 Foot Monorail Beam (2M$ per mile)
- Trucked To Construction Site With Guideway Panels Attached
- Trucked From New Jersey to Florida

Proposed MAPS Test Program: SUMMIT (Superconducting Maglev Multi Integrated Testing)

Description of SUMMIT Facility

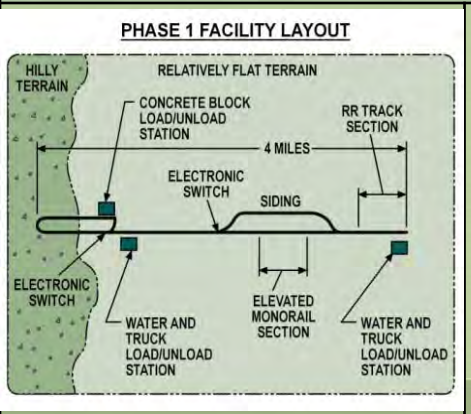
- Tests & Certifies 3 Maglev Applications on Common Guideway
- Energy Storage (MAPS)
- Long Distance Water Transport
- Highway Truck Transport
- Built in Boulder City, Nevada

Guideway Design



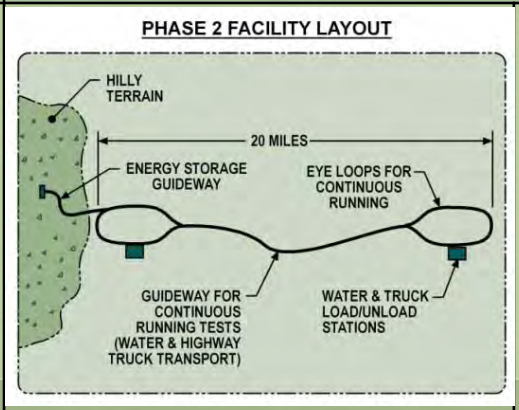
- Common Guideway & Vehicle
- 3 Vehicle Shapes
- Flat Sled (MAPS)
- Bladder (Water Transport)
- Empty Fuselage (Trucks)

Phase 1 Facility Layout



- **Proves:**
- Stable Lift Capability
- Magnetic Propulsion Capability
- Energy Efficiency
- Block Load/Unload
- Time/Cost: 3 years/ 160 M$

Phase 2 Facility Layout



- **Proves:**
- Continuous Long-Term Running Reliability
- All Weather Operation
- Time/Cost: 2 Years/ 170 M$

Summary and Conclusions

- MAPS System Can Store Large Amounts of Electrical Energy at High Output/Input Efficiency and Low Cost
  - 1000's of MWH at 90% Efficiency and 2-3 Cents/KWH
- MAPS Systems Can Be Sited at a Wide Range of Locations
  - Hilly or Flat Terrain
  - Much Less Environmental Problems and Limitations Than Pumped Hydro
- MAPS Can Store Electrical Energy From
  - Variable Wind & Solar Renewable Power Sources to Feed Grid When Appropriate
  - Baseload Plants to Meet Peak Demand Periods –Eliminate Need for Natural Gas Peak Power Plants
  - Various Sources to Stabilize the GRID in the Event of Accidents or Sabotage
- Very Large Market for MAPS Systems in US and the World – Many Thousands of Megawatts
- MAPS Technology Based on 1st Generation Maglev Transport Systems and 2nd Generation Components Already Demonstrated

Las Vegas MAPS/SUMMIT Test Site

Presented by

Robert Coullahan

Readiness Resource Group, Inc.

Las Vegas, Nevada

Nevada MAPS Test Site

Length of Time to Payback the Construction Cost of a MAPS Facility

Cost Differential Between Purchase Price of Power to be Stored & Delivery Price to Grid of Stored Power $/MWH (cents/Kwh)	Net Annual Revenue M$	Time to Payback Construction/Equipment Cost Years
30 (3)	14	10.8
50 (5)	34	4.5
100 (10)	84	1.8
150 (15)	134	1.1
200 (20)	184	0.8

Alternative Business Models

Model 1: MAPS Grid Connected Facility Buys and Sells Grid Power

Model 2: MAPS is sold or leased to existing electric utilities

Model 3: MAPS is sold to Wind and Solar Farm Operators

Nevada MAPS Test Site Program Plan

Phase 1 (24 Months from start) Total Cost $18 Million

Design and Construct:

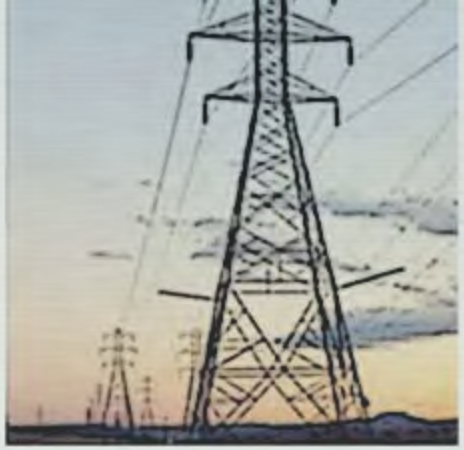
- 1 MAPS Sled w/Powered Roller Surface
- 400 feet of MAPS Guideway
- 1 Concrete Block (100 Tonne)
- 1 Powered Roller Bar Shelf
- 1 Electric power substation
- 1 Control system

Phase 2 (12 Months) Total Cost $20 million

- Add 1 Maps Sled and Create Coupled Consist
- 2 Electronic Switches
- Complete lower storage yard with circumferential guideway

Phase 3 (24 Months) Total Cost $82 million

- Complete Upper Storage Yard and Connecting Guideway
- Cast Concrete Blocks
- Build 6 additional MAPS Sleds (3 Coupled Consists)


Thank You

Questions?