Streetcar Propulsion Power: Alternatives and Considerations

APTA Streetcar and Heritage Trolley Subcommittee

James H. Graebner, Chair

T.R. Hickey, AICP, Vice Chair

Timothy R. Borchers, Secretary / Technologist

James D. Schantz, Communications / History

Martin P. Schroeder, P.E., Chief Engineer, APTA

Public Meeting
Hosted by: DC Surface Transit, Inc.
Renaissance Hotel
Washington, DC

May 6, 2010

Introduction:
American Public Transportation Association

- Leading Force in Advancing Public Transportation Since 1882
- Legislation
- Conferences – Over 20 a year
- Education and Training
- Committee Activities
- Standards Development
- Data Collection and Dissemination
- Scientific Research

APTA's Approach

- Neutral
- Apply Industry Experience
- Utilize our Experts within the Streetcar Subcommittee
  - James H. Graebner, Chair
  - Thomas Hickey, Vice Chair
  - Tim Borchers, Secretary & Technology
  - James Schantz, History and Data

Presentation Outline

- Streetcar Overview
- Conventional Power Systems
- Alternative Power Systems
- Energy Storage Technology
- Implementation and Operation
- Summary

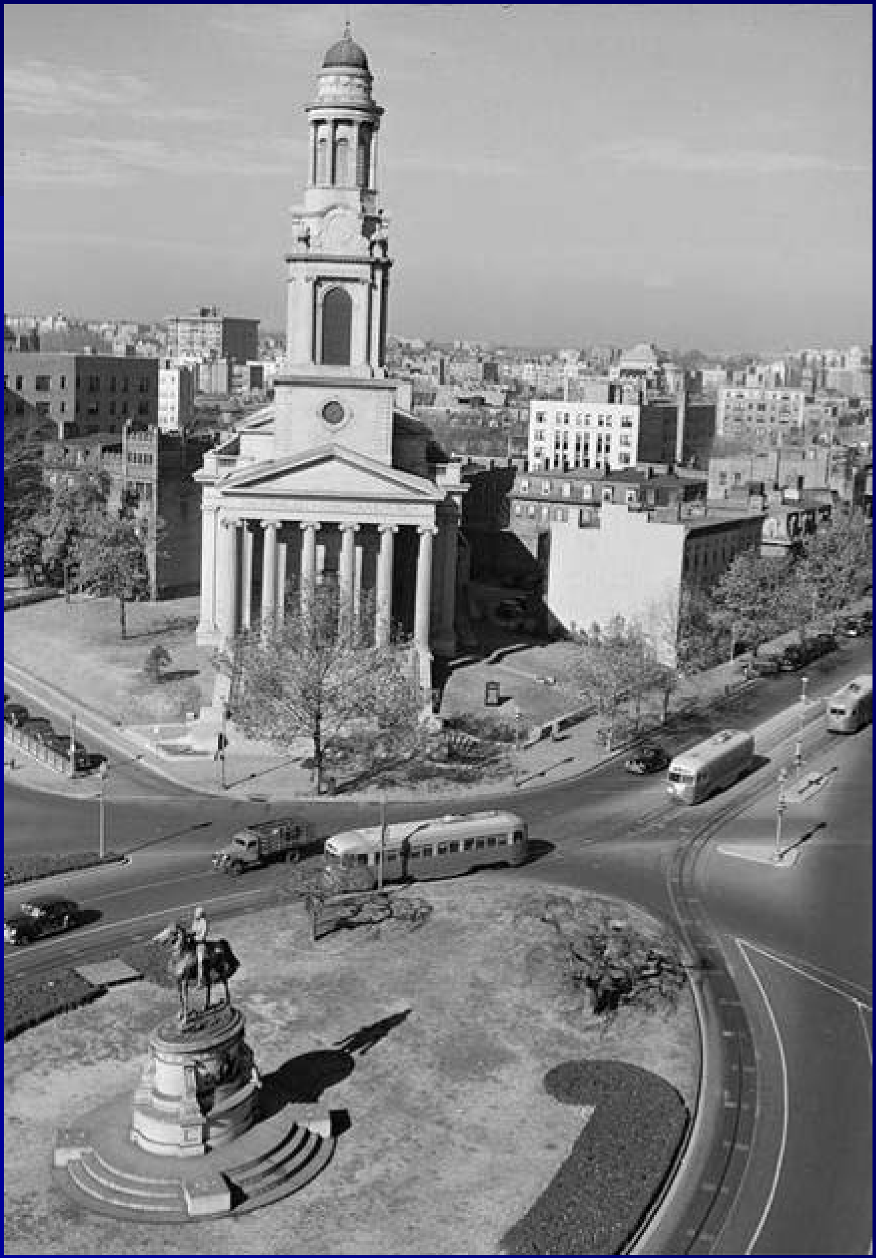
Streetcar Overview

James H. Graebner

Chair, APTA Streetcar and Heritage Trolley Subcommittee
President, Lomarado Group
Denver, Colorado

DC Streetcars

- 1862 – 1962
  Streetcar Era
- 1888 – 1895
  Technology
  Turmoil

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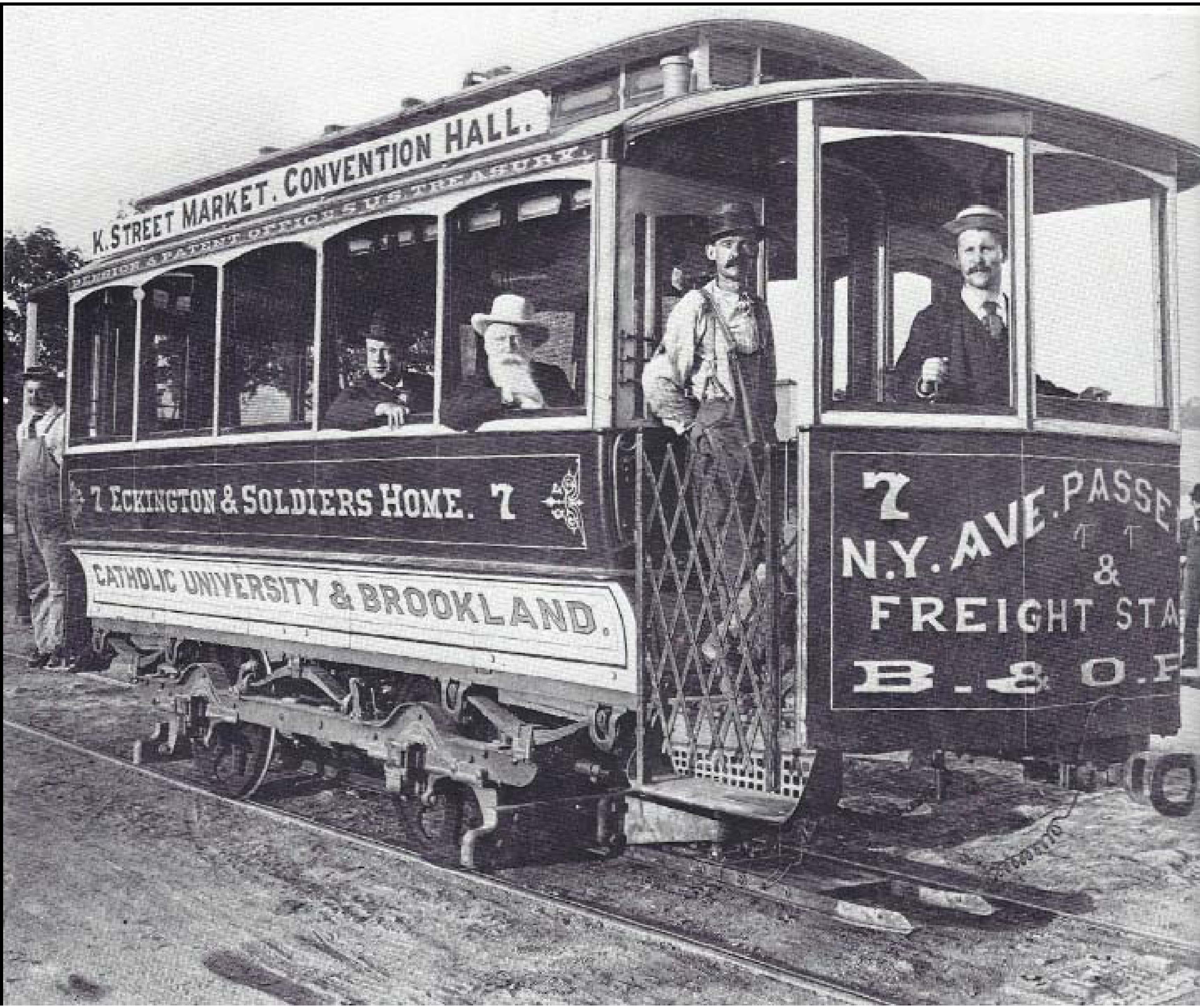
CAPITOL VIA PENNA. AV. & 14. ST.
WASHINGTON & GEORGETOWN R. R.


K. STREET MARKET. CONVENTION HALL.
7 ECKINGTON & SOLDIERS HOME. 7
CATHOLIC UNIVERSITY & BROOKLAND.
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FREIGHT STA
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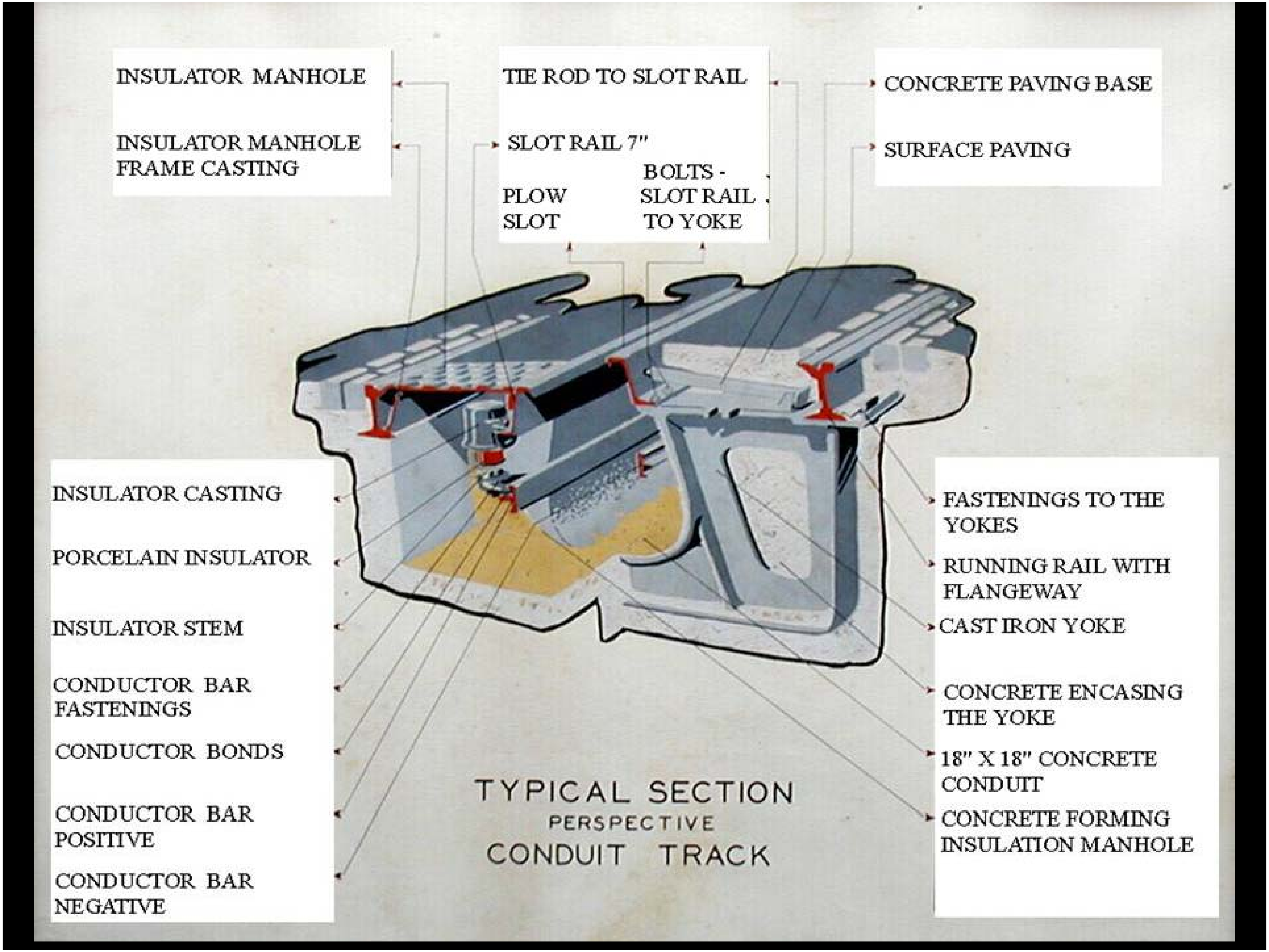
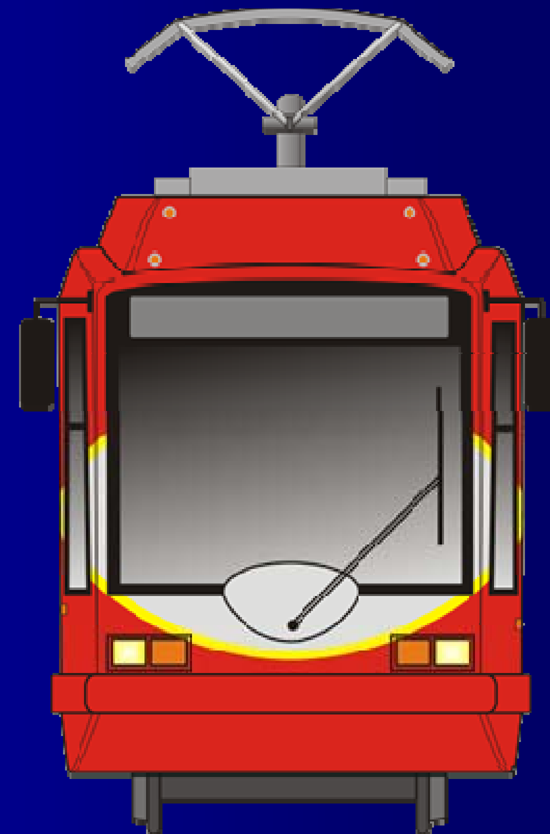

INSULATOR MANHOLE
INSULATOR MANHOLE FRAME CASTING
TIE ROD TO SLOT RAIL
SLOT RAIL 7"
PLOW SLOT
BOLTS - SLOT RAIL TO YOKE
CONCRETE PAVING BASE
SURFACE PAVING
INSULATOR CASTING
PORCELAIN INSULATOR
INSULATOR STEM
CONDUCTOR BAR FASTENINGS
CONDUCTOR BONDS
CONDUCTOR BAR POSITIVE
CONDUCTOR BAR NEGATIVE
FASTENINGS TO THE YOKES
RUNNING RAIL WITH FLANGEWAY
CAST IRON YOKE
CONCRETE ENCASING THE YOKE
18" X 18" CONCRETE CONDUIT
CONCRETE FORMING INSULATION MANHOLE
TYPICAL SECTION
PERSPECTIVE
CONDUIT TRACK

303
303
THE CAPITAL TRACTION CO


1319

DC Streetcars – *Then and Now*

The fundamentals remain the same despite outward changes in appearance and upgrades in technology.



Streetcar Power Systems

- External power supply or generated on-board
- Continuous or not
  - If not continuous, on-board storage system is needed

Which approach (or combination of approaches) best suits the needs of the District?

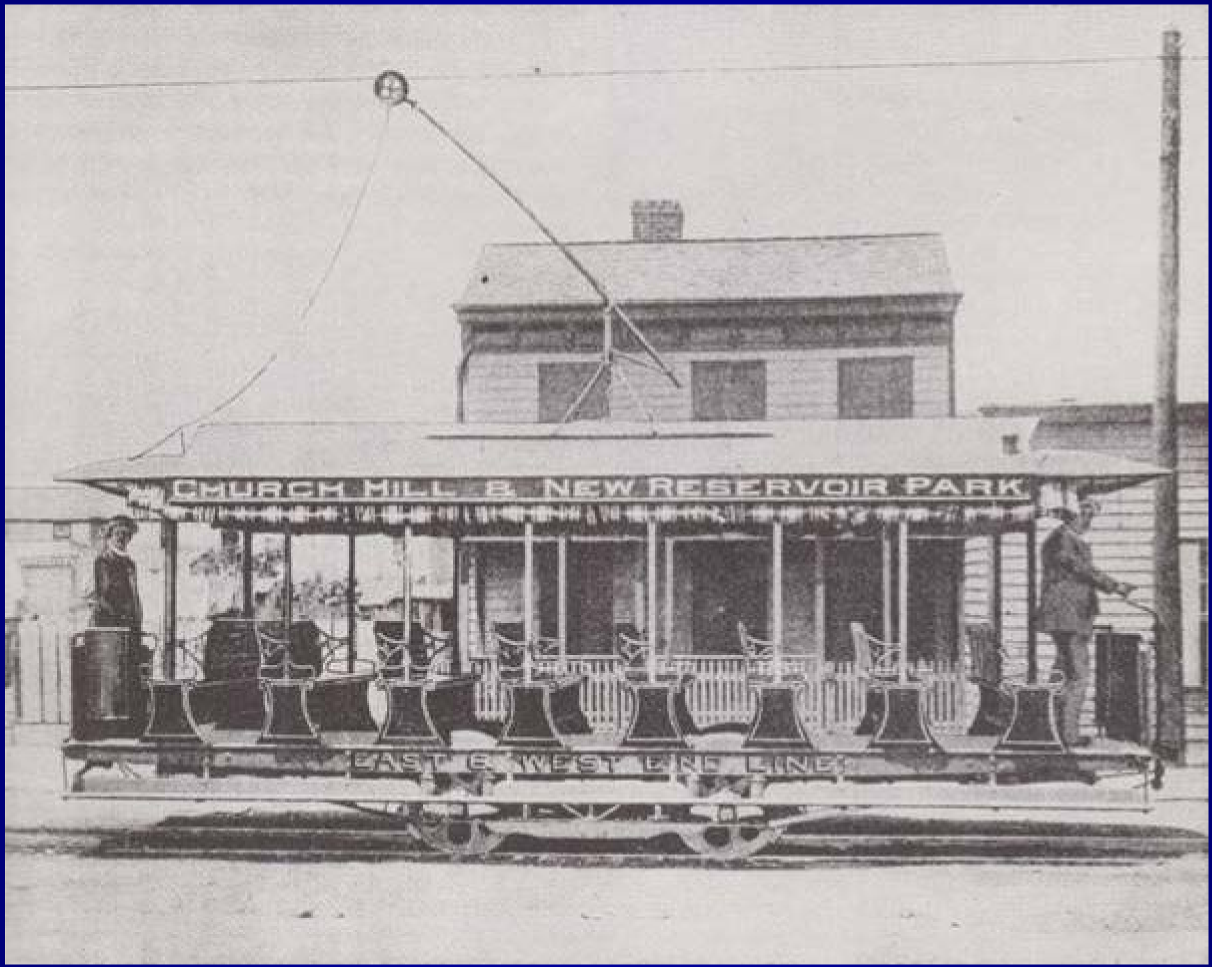
Conventional Power Systems

James D. Schantz

APTA Streetcar and Heritage Trolley Subcommittee
Chairman, Board of Trustees
New England Electric Railway Historical Society
Kennebunkport, Maine

19th Century: Experimentation

19th Century: Success



20^{th} Century: Standard Practice

Trolley Wire: What is is *not*...

Trolley Wire: What it is *not*...

Trolley Wire: What it *is*...

Trolley Wire: Poles and Spans

Trolley Wire: Poles and Spans

Trolley Wire: Building Anchor

Trolley Wire: Building Anchor

Trolley Wire: Building Anchor

Trolley Wire: Bracket Arm

Trolley Wire: Bracket Arm

Trolley Wire: Curves

Trolley Wire: Curves

Trolley Wire: Summary

- Used for 120 years around the world
- Inexpensive to build and maintain
- Half inch diameter, 18 feet up
- Visual intrusion can be minimized

Conduit: Only Widely Used Alternative

Conduit: Only Widely Used Alternative

Alternative Power Systems

Timothy R. Borchers

APTA Streetcar and Heritage Trolley Subcommittee
Principal, City Rail Solutions
Tampa, Florida

Alternatives to Overhead Contact System (OCS)

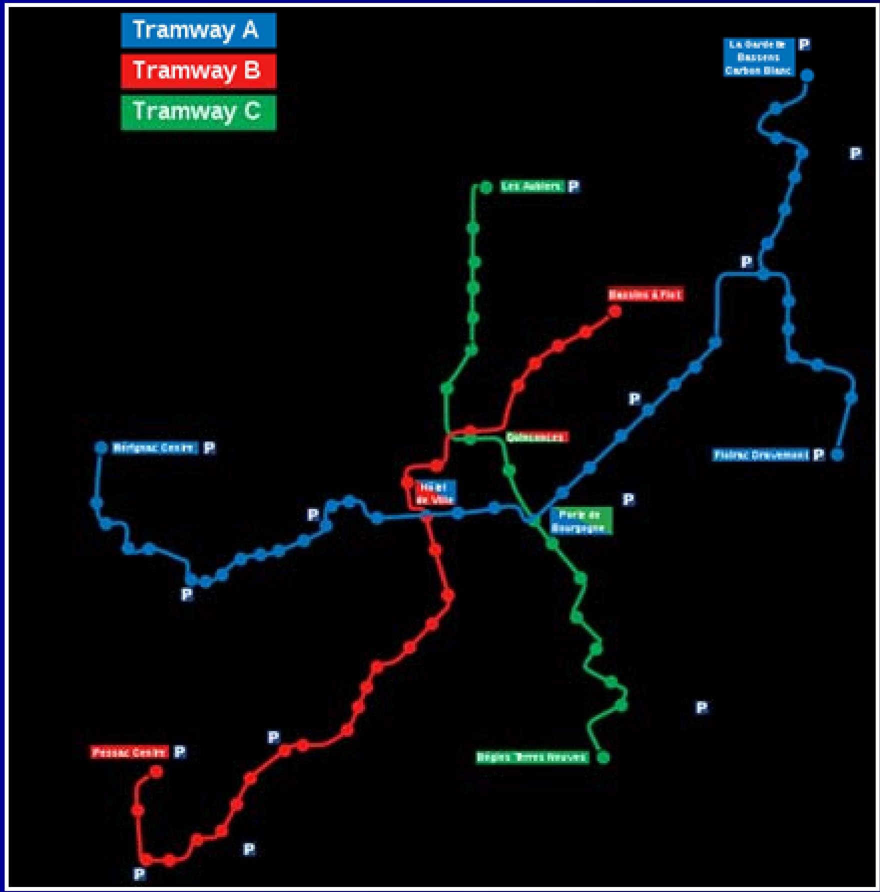
- Ground level power supply.
- On-board electric energy storage (batteries, flywheels, super or ultra capacitors)
- On-board electric energy generation (internal combustion engine, fuel cell)

*Ground Level Power Supply Innorail/APS

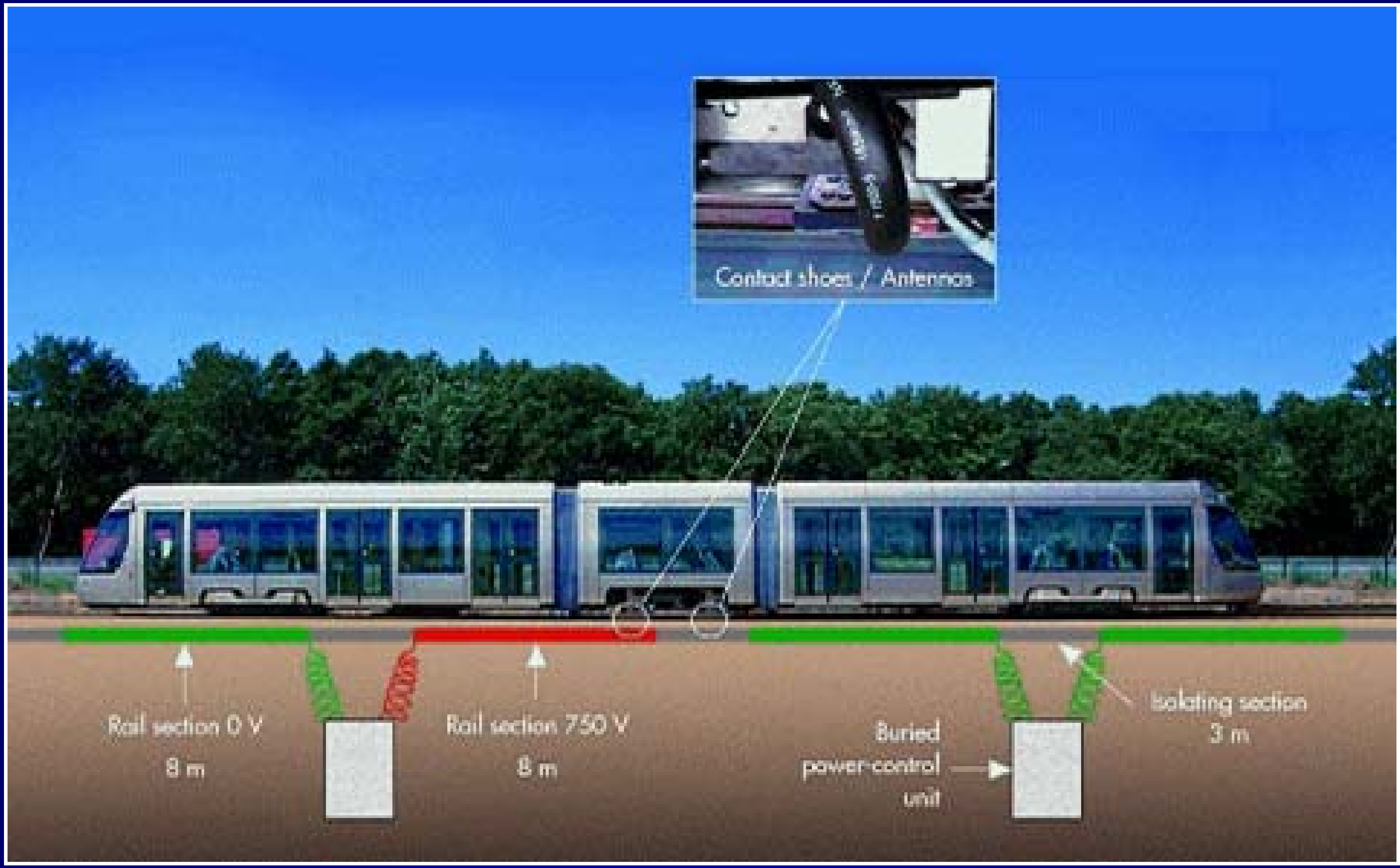
Ground Level Power Supply Innorail / APS

- Bordeaux France
- Daily ridership 165,000
- Total system length 43 km (27 mi)
- 12 km of APS
- 74 Citadis trams

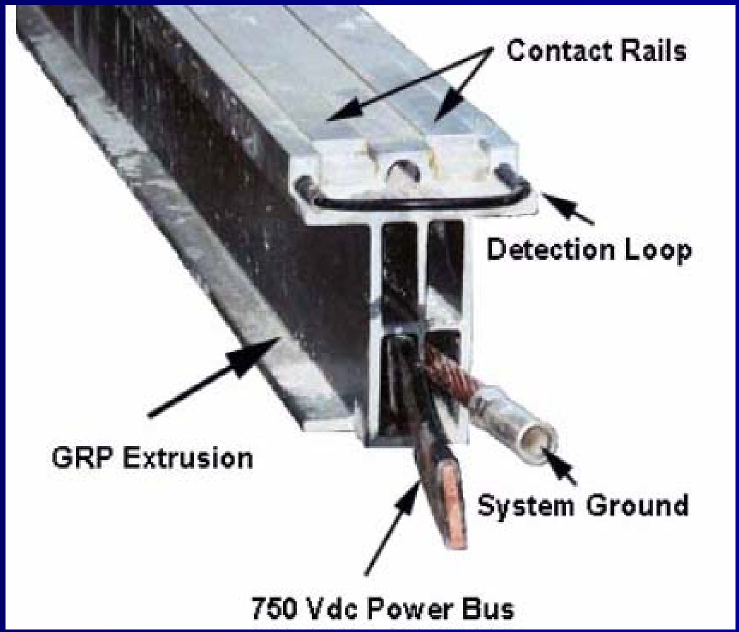
The Alstom Innorail or Ground-level power supply, is also known as surface current collection and Alimentation par Sol (APS)

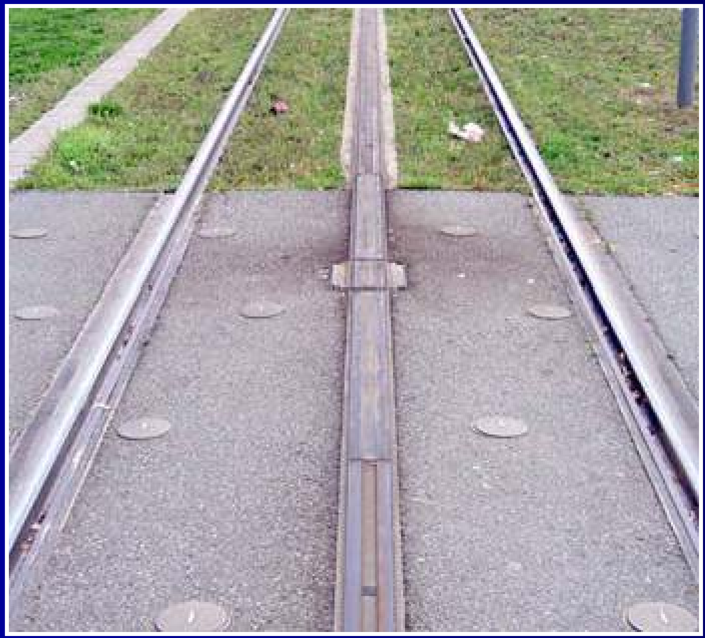


Ground Level Power Supply
Innorail / APS



Ground Level Power Supply
Innorail / APS





The system had a number of “teething” problems, poor drainage and debris on the contact strips caused service unreliability. Reliability has improved and one kilometer of surface contact replaced with OCS. Reliability under heavy ice and snow conditions has not been established.

Ground Level Power Supply Innorail / APS

Ground Level Power Supply Innorail / APS

Ground Level Power Supply Innorail / APS

- Sources suggest that in Europe APS adds about US $130,000 to the cost of each tram, while the infrastructure is about 300% more expensive than overhead wires.
- Several new French and European tram systems will use APS over part of their networks.
- The planned Al Sufouh Tramway in Dubai will use APS exclusively.

*Ground Level Power Supply - Primove

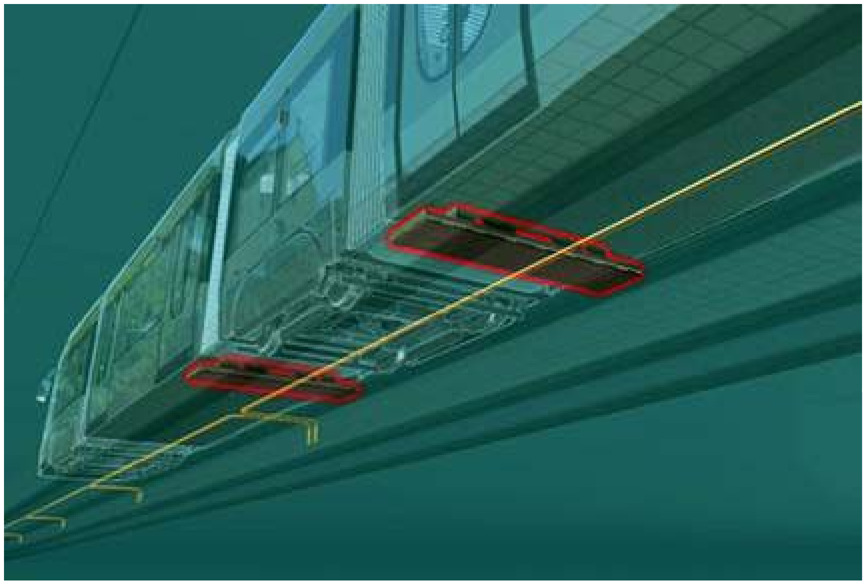
Primove was unveiled by Bombardier on Jan. 2 2009.

It uses a magnetic field to transmit power from a circuit built into the track to pick-up coils beneath a tram. These coils transforms the magnetic energy into electricity which charges super capacitors on the tram.

The in-ground equipment is energized only when covered by the vehicle. The prototype provided sufficient power for a 98-ft.-long (30 meter) LRV operating at 25 mph (40 kph) on a six-percent grade.

Bombardier Primove market-ready in 2010.

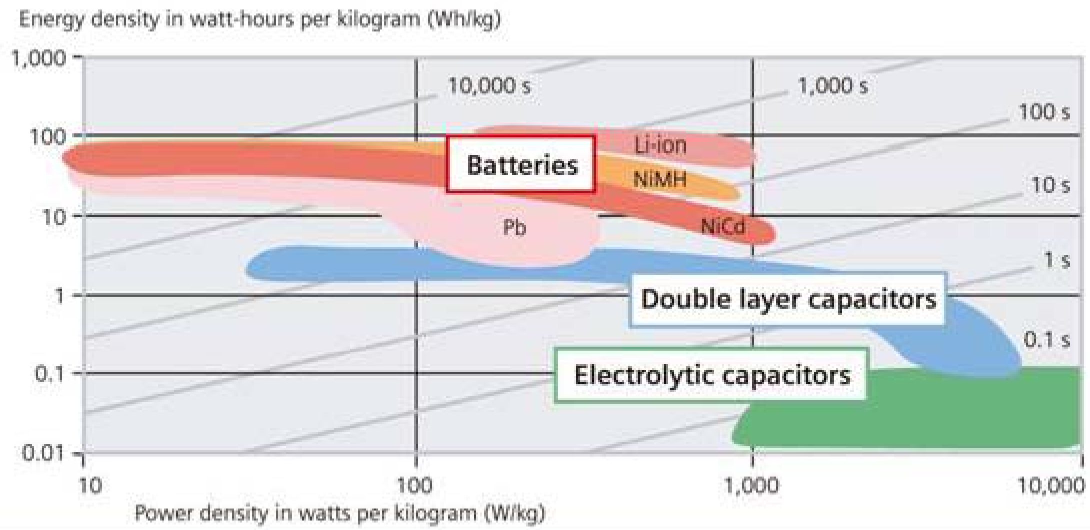
Ground Level Power Supply - Primove



Using inductive power to charge super capacitors to power the tram.

On-board electric energy storage (batteries, flywheels, super capacitors)

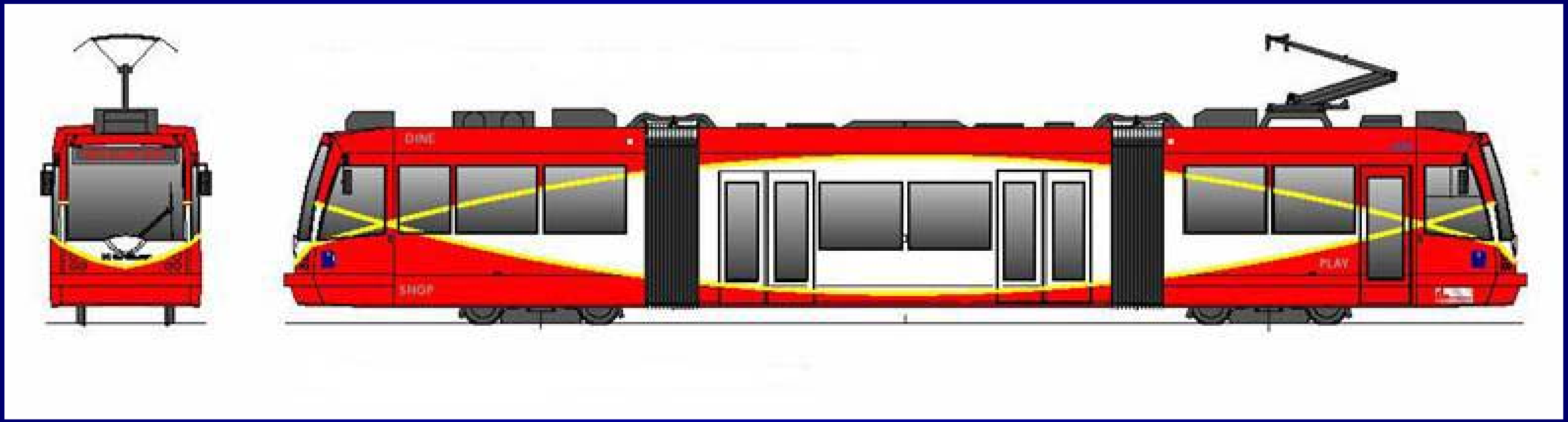
Comparison of Battery Systems



Battery type	Energy density Wh/kg	Power density W/kg	Service life in cycles / years
Lead-acid battery	30 – 50	150 – 300	300 –1,000 / 3 – 5
Nickel-metal hydride battery	60 – 80	200 – 300	>1,000 / >5
Lithium-ion battery	90 – 150	500 – >2,000	>2,000 / 5 – 10
Supercaps (double layer capac.)	3 – 5	2,000 – 10,000	1,000,000 / unlimited

*On-board electric energy storage batteries - Trio Streetcar

Skoda, Inekon and United Streetcar Trio type streetcars may operate wireless in the maintenance facility or through an intersection in the case of OCS power failure.



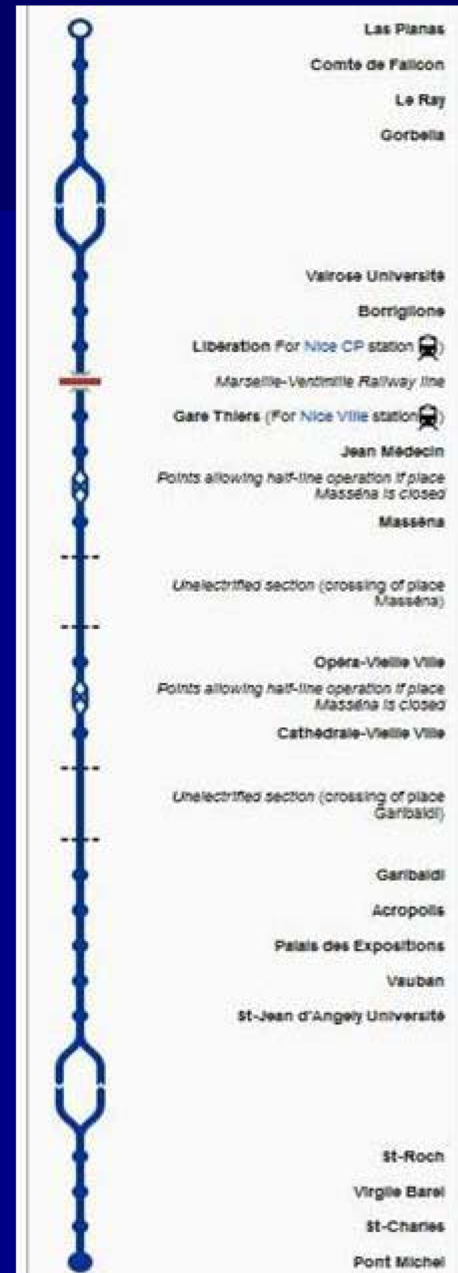
*On-board electric energy storage batteries – Nice France

Nice France

- Opened early 2007
- System Length 8.7 km (5.4 mi)
- Alstom Citadis with batteries
- 20 trainsets
- Daily Ridership 70,000

On-board electric energy storage batteries – Nice France

- No OCS on 2 squares , Place Massena (435 m) & Place Garibaldi (485 m).
- Use of roof- fitted NiMH (nickel-metal hydride) batteries capable of providing up to 1km of travel at 30km/h.



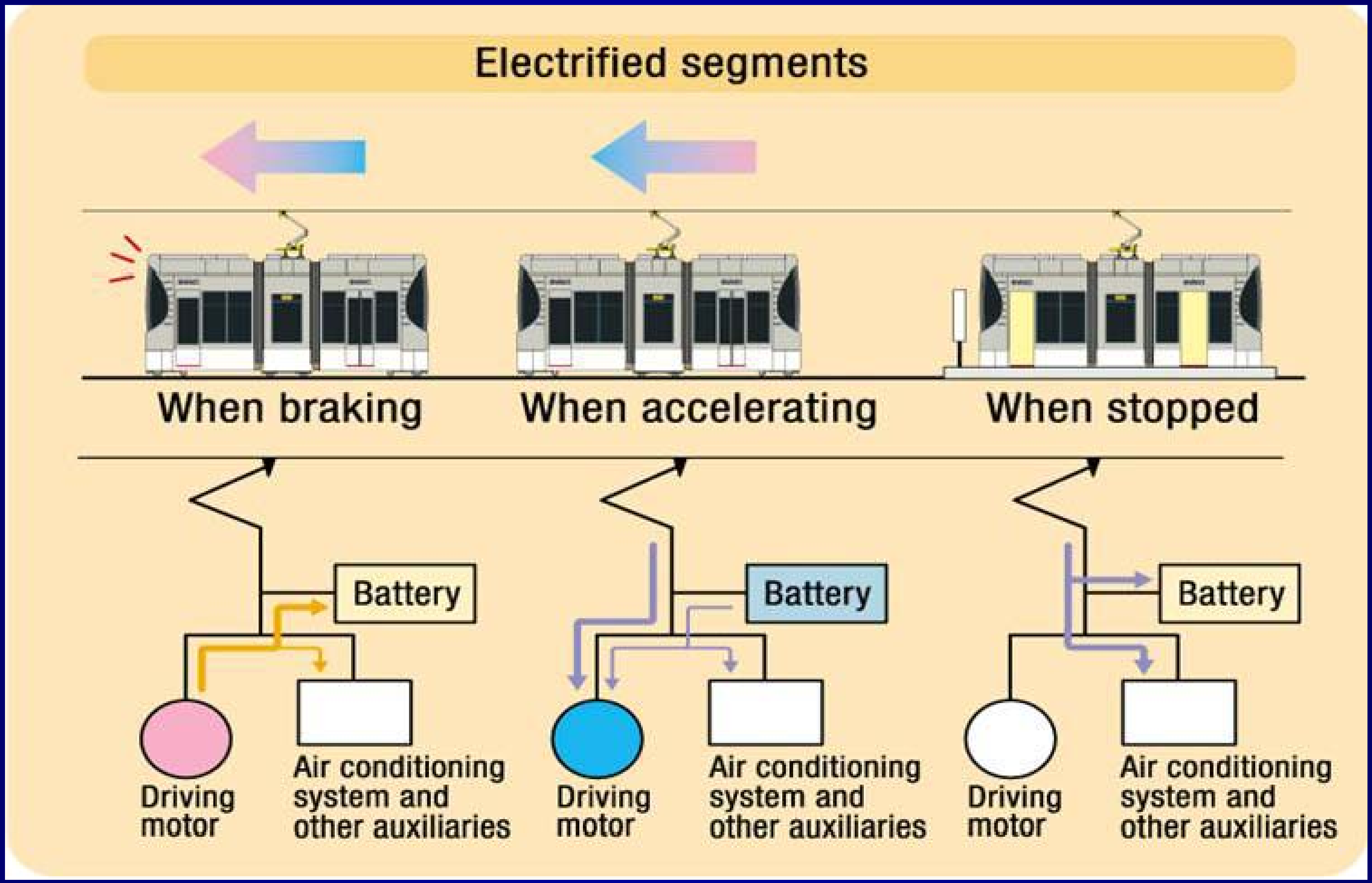
*On-board electric energy storage batteries – SWIMO Battery Tram

Kawasaki SWIMO Battery Car, can operate for 10 kilometers (6 miles) on a single charge of 5 minutes.

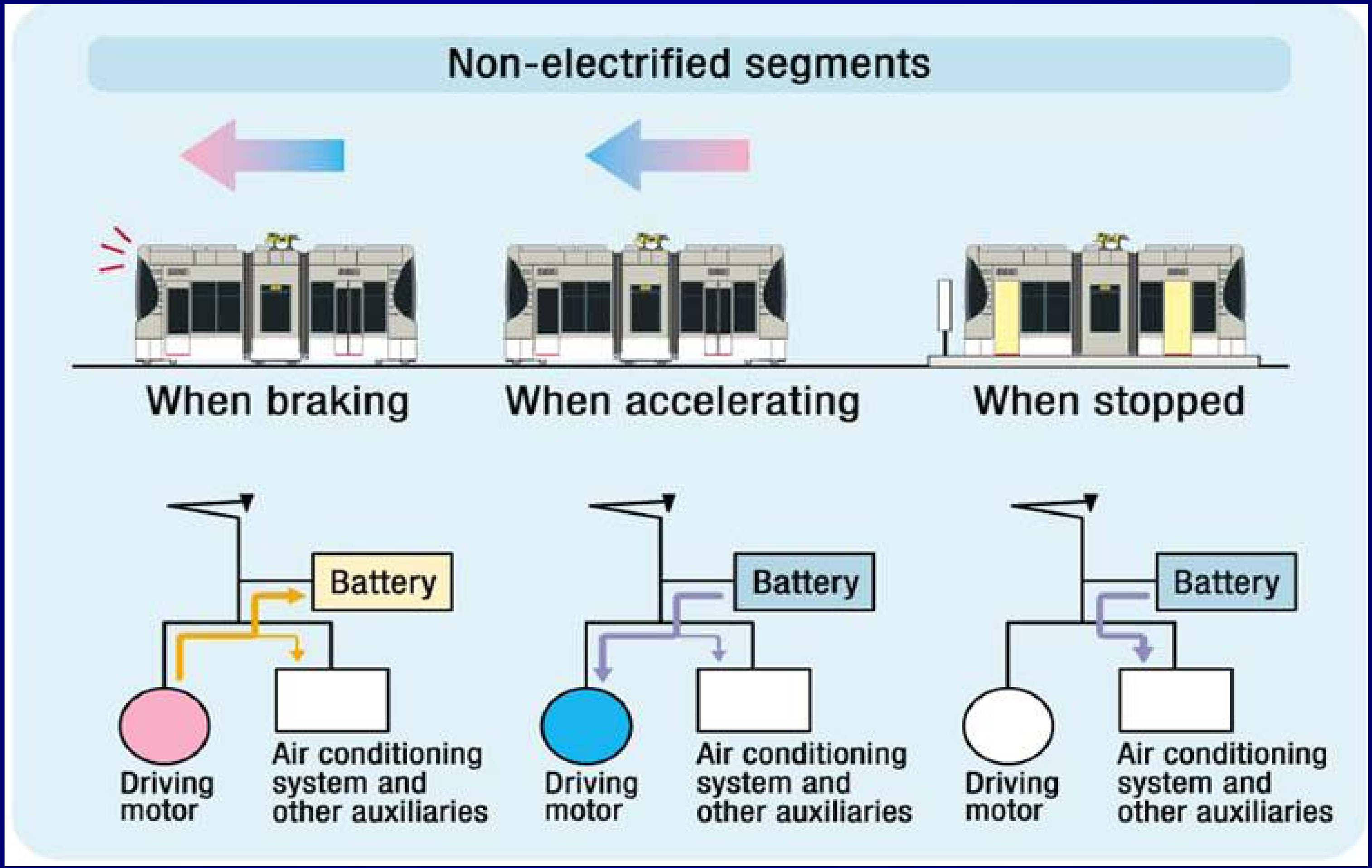
In trials, the best performance was 37.5km without re-charging. Between December 2007 and March 2008, trial runs were undertaken in Sapporo City Japan.

Onboard batteries are nickel-metal hydride.

On-board electric energy storage batteries – SWIMO Battery Tram



On-board electric energy storage batteries – SWIMO Battery Tram



*On-board electric energy storage flywheel.

In Rotterdam, the Netherlands, Alstom the flywheel. It stores kinetic energy from braking and can be re-loaded on sections with OCS to again deliver energy over an OCS section of up to 2 kilometers at 50 kph.

On-board electric energy storage flywheel.

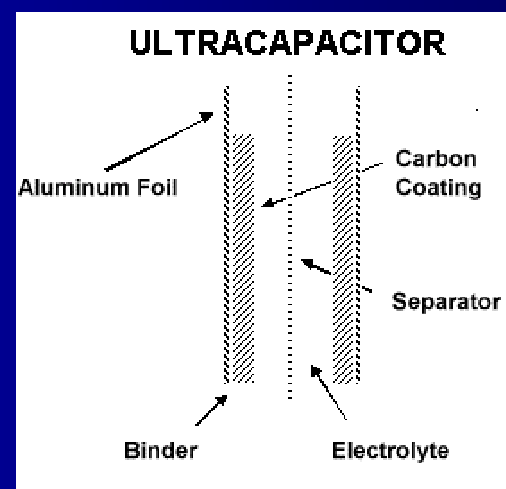
A carbon fibred rotating permanent magnet motor-generator located on the roof of the tram works on the same principle as a spinning top.

The kinetic energy stored during braking is restored by the electric generator is returned to the propulsion system when the tram accelerates.

The system is recharged each time the brakes are applied or by a complementary high-speed recharging system each time the tramway stops at a station.

*Power Systems – Storage Capacitors

- Theory behind electrochemical (EC) or double layer capacitors (DLC) known for over 100 years, not until the 1960s was developed as a functional energy storage device.
- Known also as Super or Ultra Capacitors.
- Super capacitors or Ultra capacitors used by the US military to start the engines of tanks and submarines.



On-board electric energy storage super or ultra capacitors.

Banks of Supercaps on the roof of a Scania bus.

*On-board electric energy storage super or ultra capacitors - Mitrac.

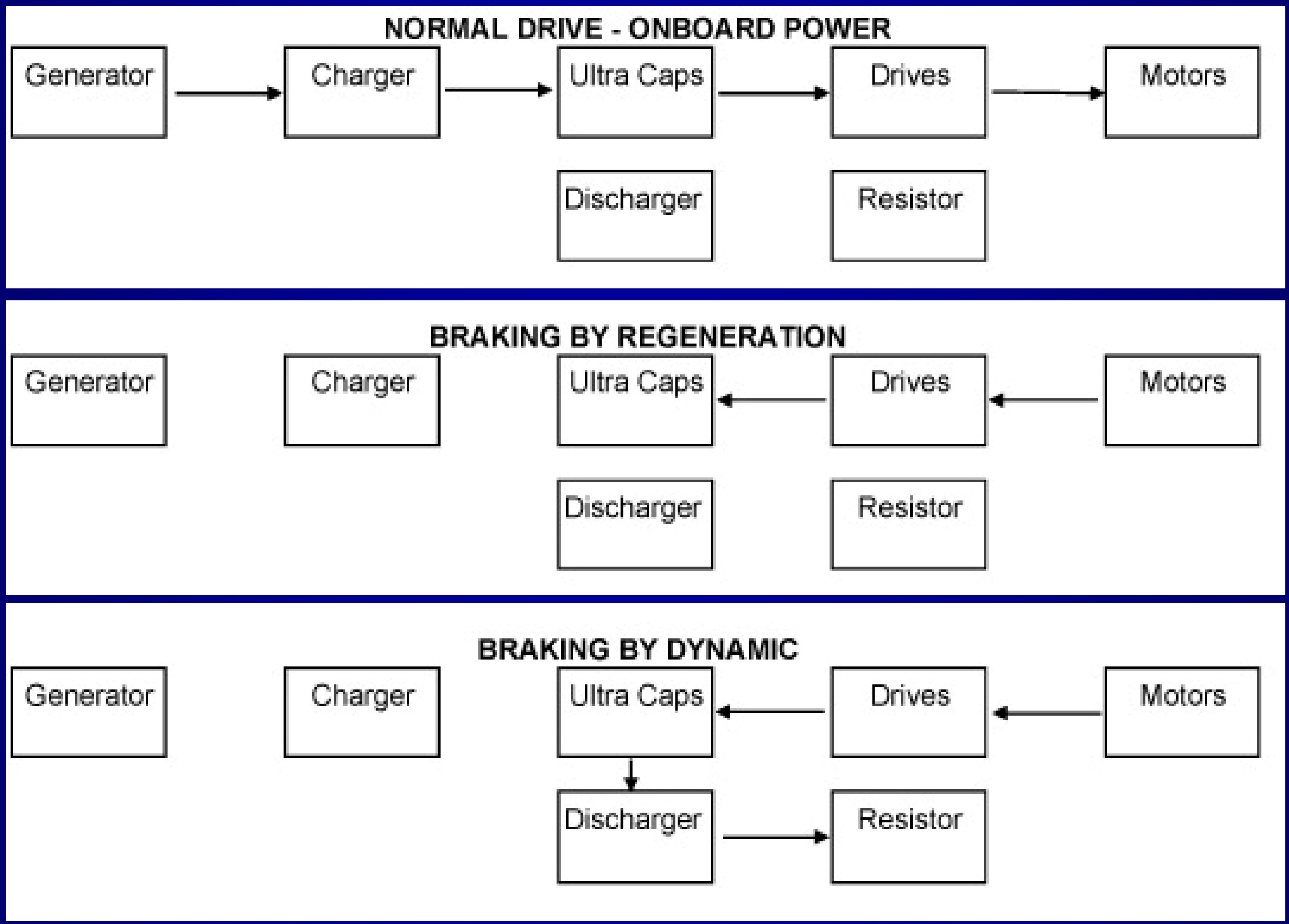
- The PRIMOVE system uses Bombardier MITRAC Energy Saver which ensures continuous vehicle operation.
- Mitrac stores energy during braking and constantly charges during operation, picking up power from the underground section during OCS free operation. Enables OCS free operation over limited distances
- Combination of capacitors and storage cells.

*On-board electric energy storage super or ultra capacitors - Savannah.

- Developed and built by Electric Motor & Supply in Altoona Pennsylvania in 2008 in response to City of Savanna's requirements.
- 100% US.
- May operate with or without OCS.
- Based on Allen-Bradley distributed Rockwell Automation and other off the shelf components with some custom made devices.
- 100% super capacitor powered.
- Operating passenger service since February 2009.

On-board electric energy storage super or ultra capacitors - Savannah.

*On-board electric energy storage super or ultra capacitors - Savannah.



*On-board electric energy storage super or ultra capacitors - ACR.

Construcciones y Auxiliar de Ferrocarriles (CAF) Rapid Charge Accumulator ACR (Spanish initials).

- CAF will install its new OCS free system along a 1.6 km of route of visual significance in Seville (Spain).
- The CAF joint venture has been selected to supply 13 low-floor trams with energy storage for Granada's (Spain) initial 15·9 km light rail route.
- Supply ACR solutions for Zaragoza (Spain) tramway. Zaragoza is currently developing a project for the construction of a tram network, half of which is equipped with an OCS system.

On-board electric energy storage super or ultra capacitors- ACR.

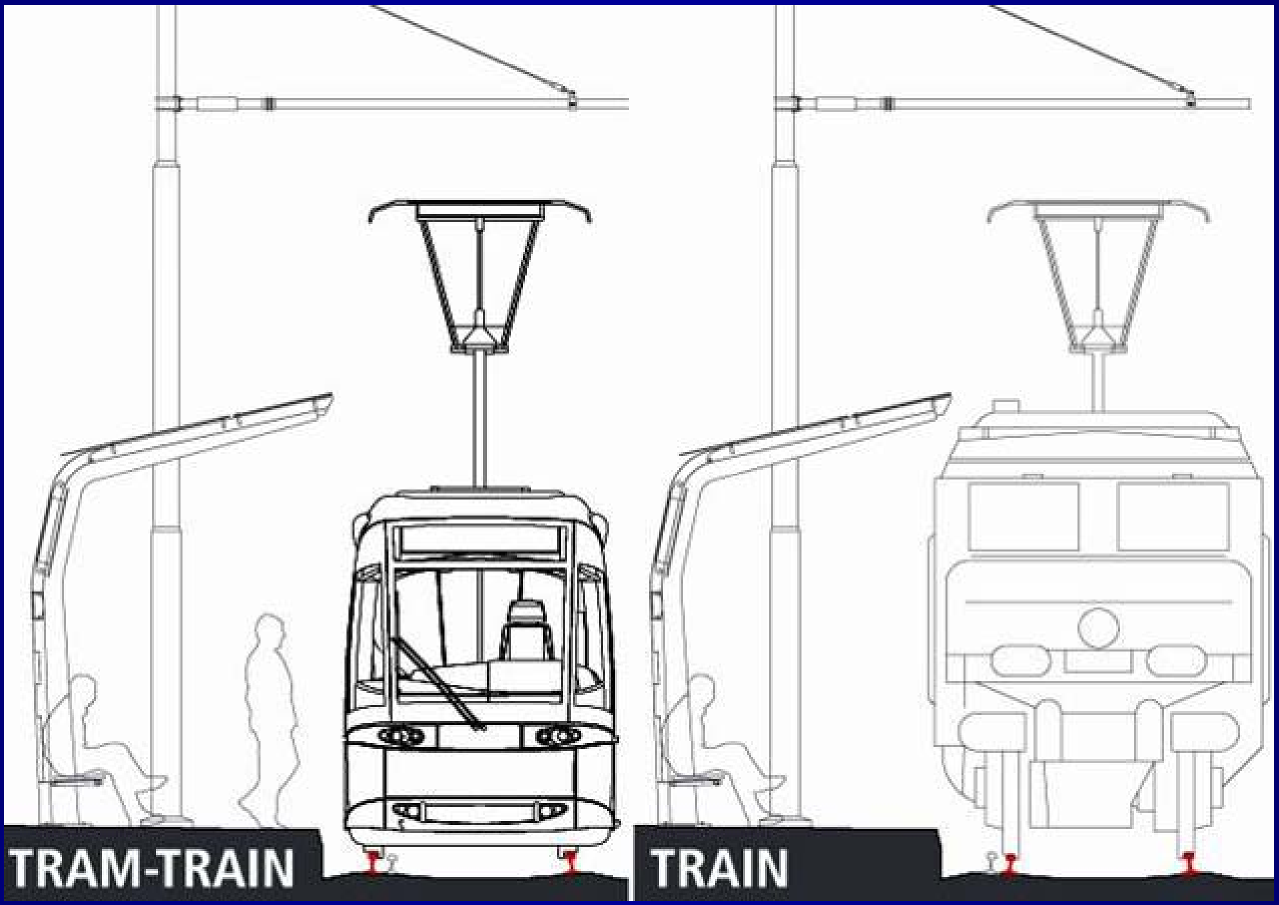
CAF ACR System

- Up to 1200 meters of OCS free running range depending on route characteristics between stops or incidents on the line .
- Modular and scalable .
- Suitable for use on existing systems
- 20 second charge times, compatible with stopping times at stations .
- Non-captive system (material/infrastructure independent) .

*On-board electric energy storage super or ultra capacitors- Sitras.

- Siemans Sitras system can operate without an overhead contact system for 2,500 meters.
- Can can be retrofitted to existing vehicles, infrastructure remains unaffected.
- In Portugal, the system has been successfully used in passenger services since November 2008.
- Certified according to BoStrab (German Construction and Operating Code for Tramways).
- The system consists of double-layer capacitors and nickel-metal hydride batteries mounted on roof surfaces.

*On-board electric energy storage internal combustion engine – Tram/Train.



*On-board electric energy storage internal combustion engine – Tram/Train.

Alstom

Regio CITADIS (tram) and CITADIS Dualis (Light Rail).

All current railway power supply systems and high performance diesel traction may be incorporated. Full low floor between the first and last doors, Regio CITADIS can carry up to 800 passengers.

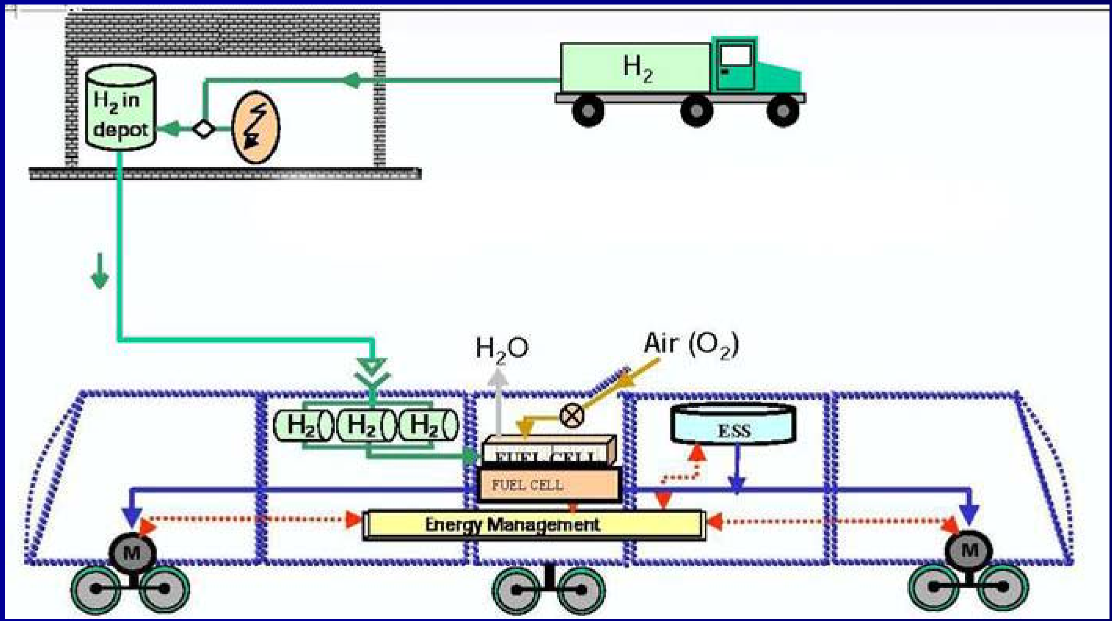
*On-board electric energy storage (internal combustion engine, fuel cell).

Siemans

A Nordhausen (Germany) Siemans ‘DUO’ Combino linking the urban tramway, where it is electrically powered via overhead wires, and the rural railway, where it is powered by an onboard diesel engine.

*On-board electric energy storage fuel cell.

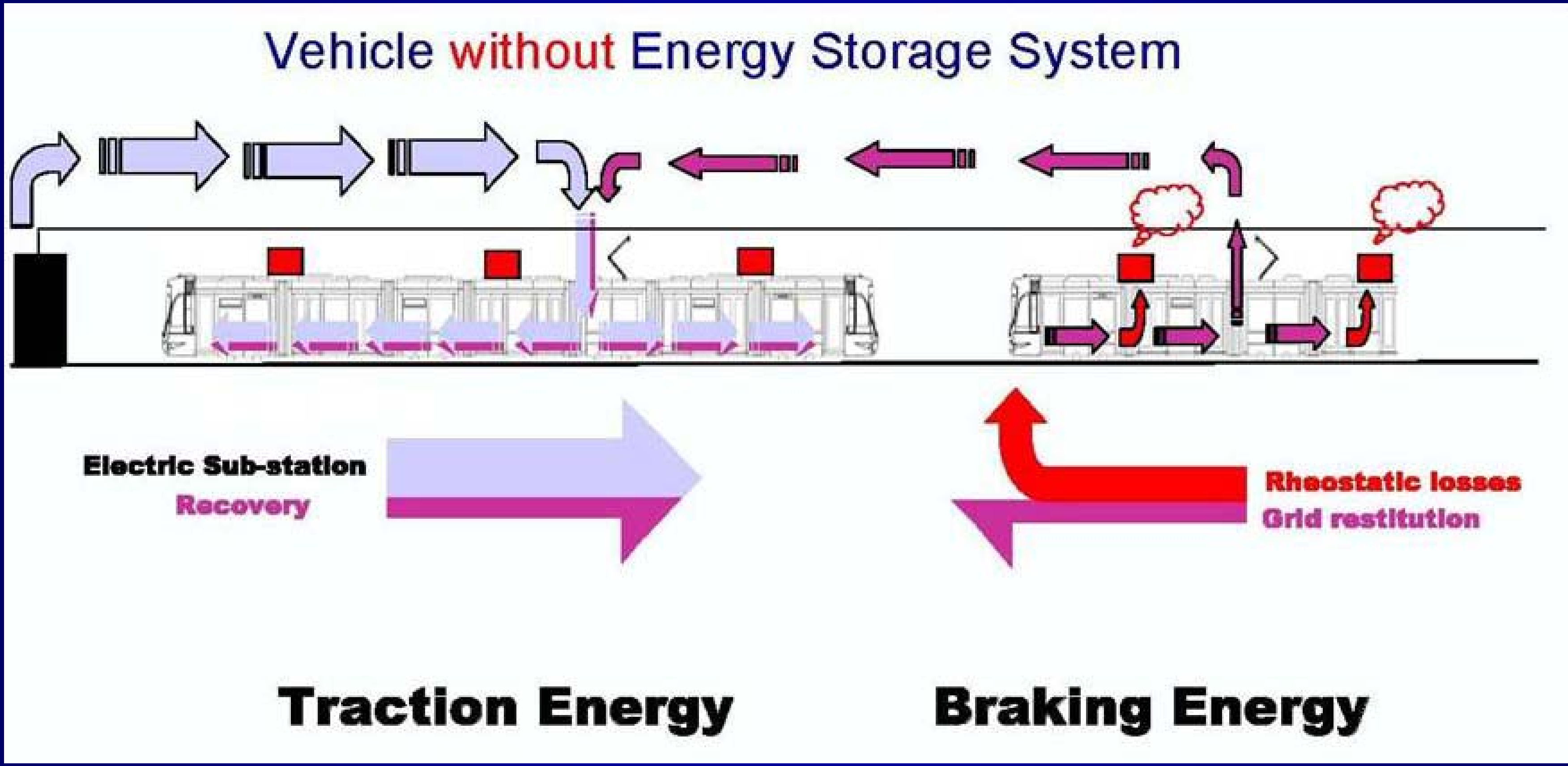
- No overhead Contact Line.
- Hybrid traction system onboard energy storage allows braking energy recovery and supplies power
- Hydrogen storage, compression and distribution in the maintenance facility.
- On-board hydrogen storage.



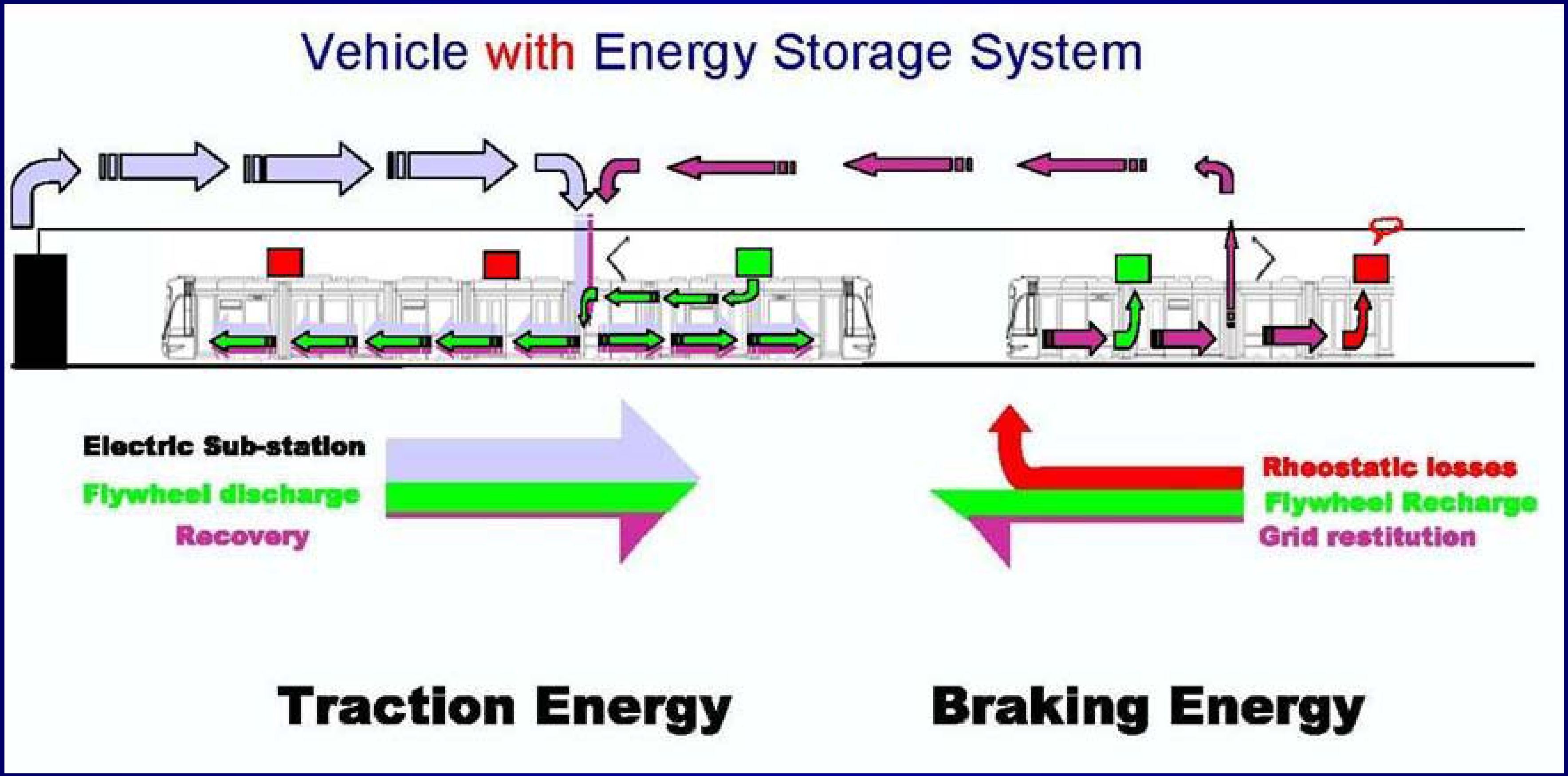
On-board electric energy storage fuel cell.

- State requirements and recommendations for future streetcar generations.
- Experimental streetcar in real operation conditions with passengers.
- Size and type of plant required.
- Production and distribution.
- Assess economical feasibility (Life Cycle Cost)
- Lifetime objective same as actual streetcar systems around 30 years.

*On-board electric energy storage



On-board electric energy storage



Energy Storage Technology

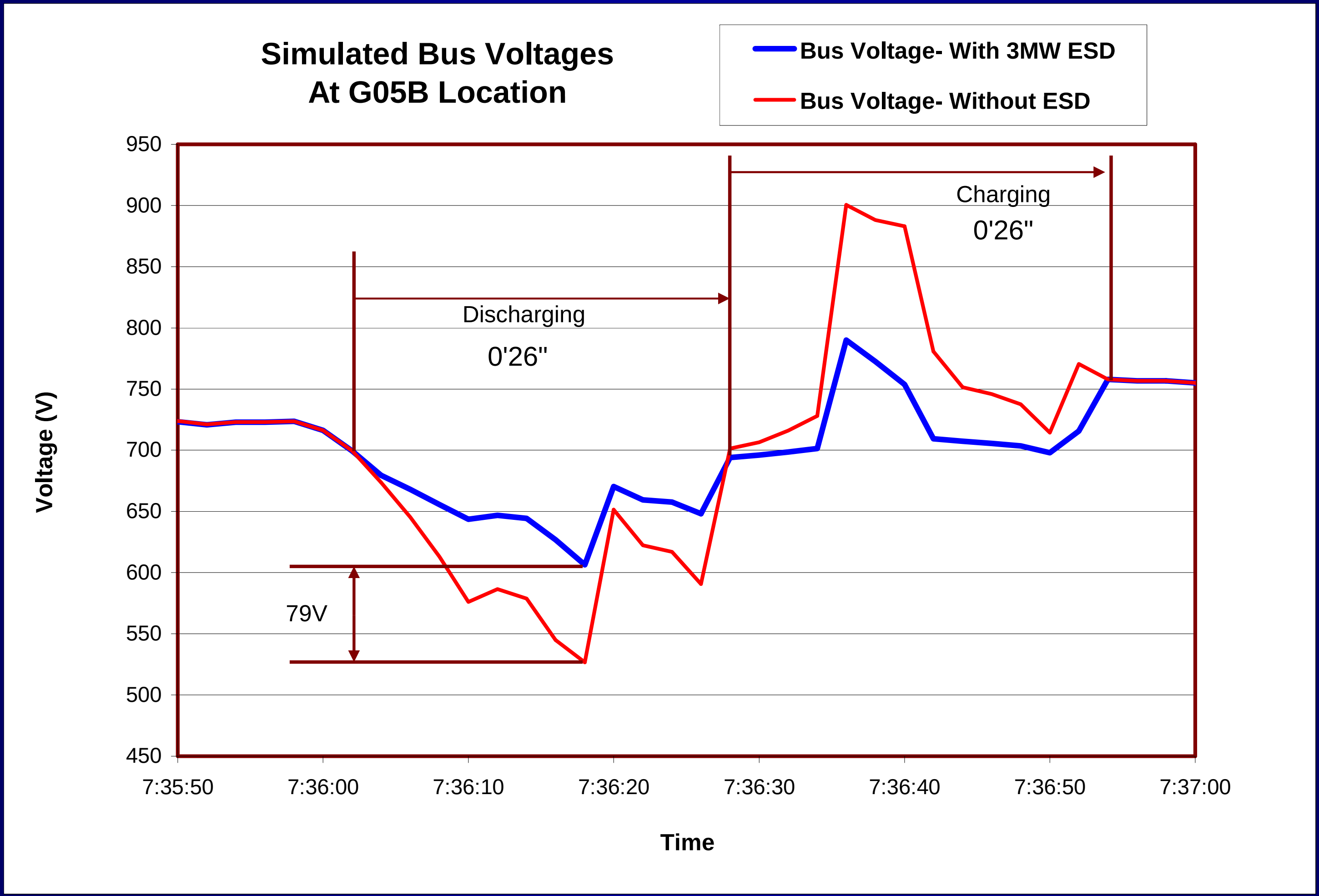
Martin P. Schroeder, P.E.

APTA Streetcar and Heritage Trolley Subcommittee
Chief Engineer, American Public Transportation Association

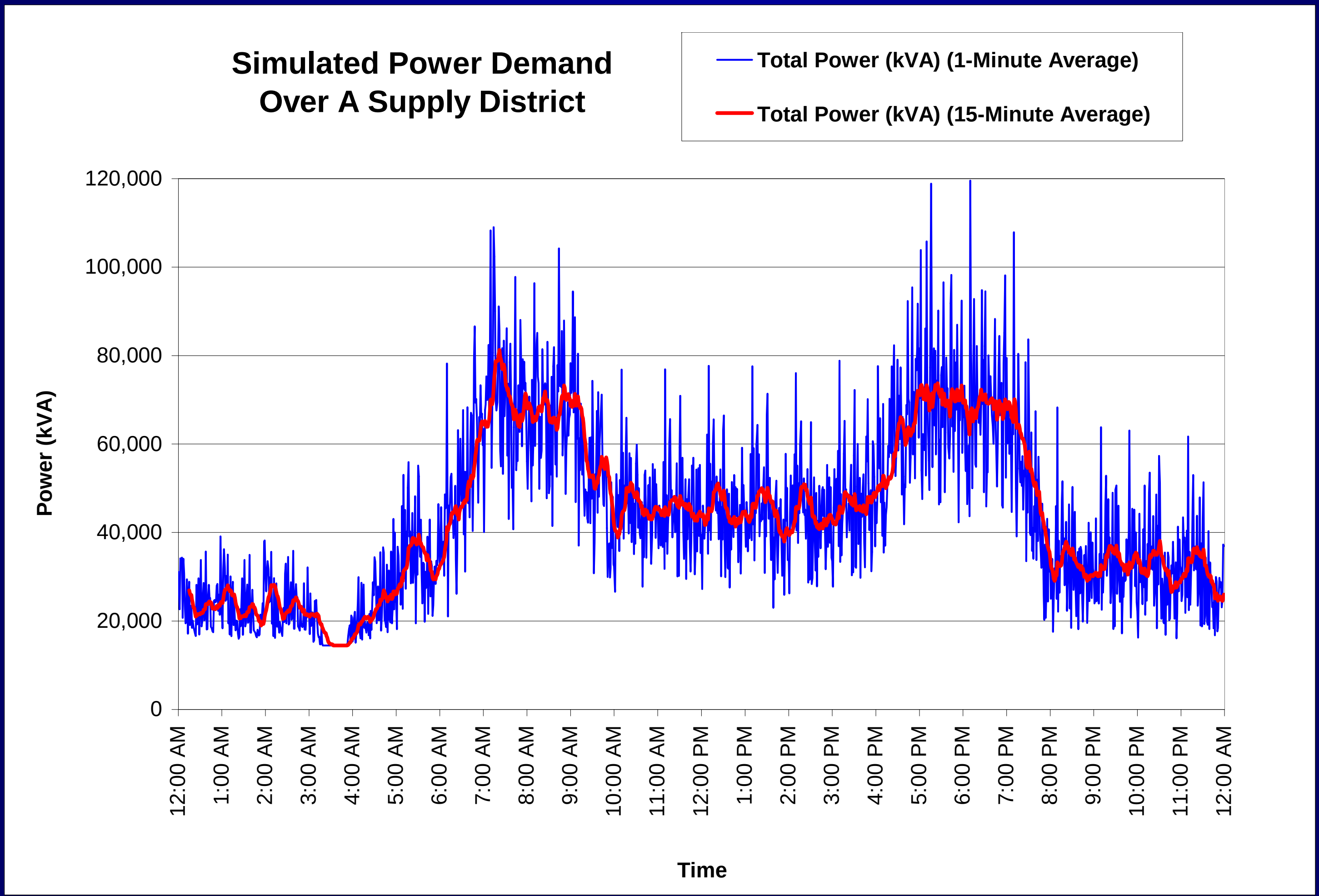
Energy Storage Benefits

- Braking Energy Capture
- Voltage Sag Correction
- Reduction of Line Energy Demand
- Power Leveling
- Reduction of Substations
- Wireless Operation

Voltage Sag Problems



Peak Power Problems



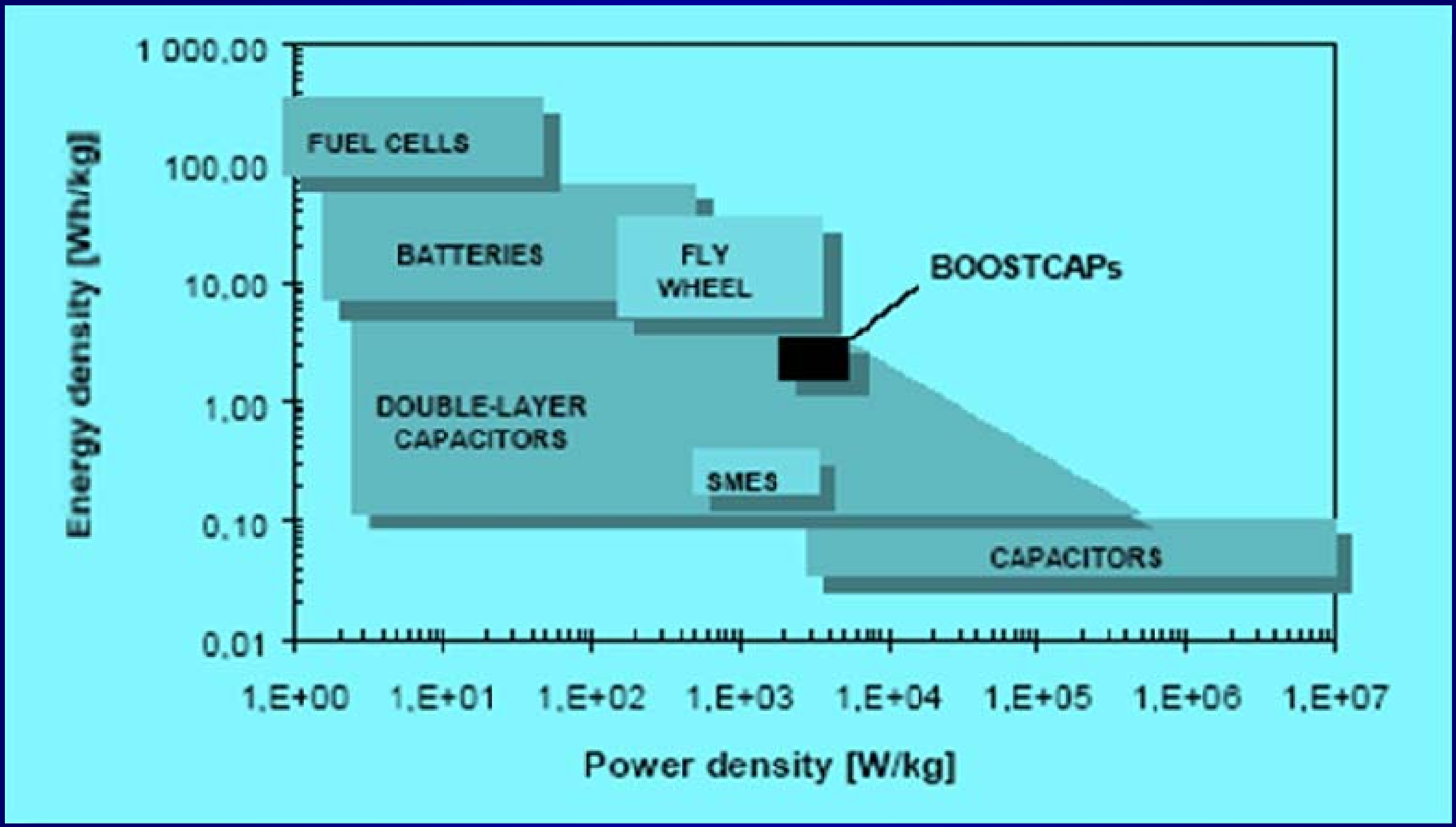
Example Types of Energy Storage

- Lead Acid
- Nickel Metal Hydride (NiMH)
- Lithium Ion (Li-ion)
- EC Capacitor
- Fuel Cells
- Flywheel
- Flow Batteries
- REDOX

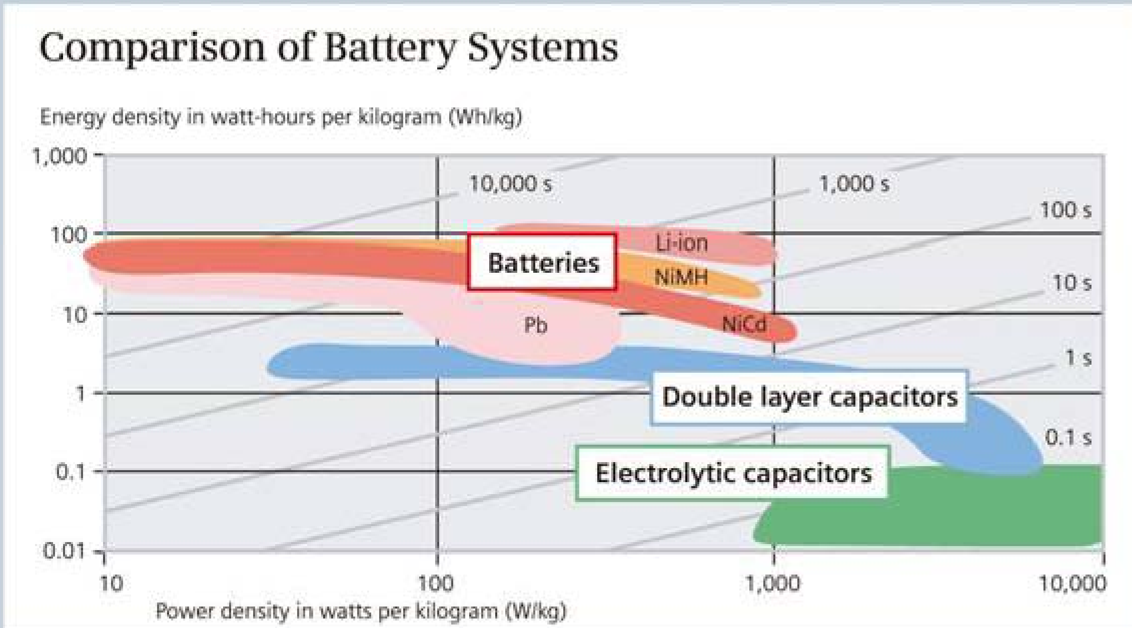
Energy Storage Performance Measures

- Capacity
- Cycle Depth
- Cycle Frequency
- Voltage
- Internal Resistance Efficiency
- Operating Temperature
- Shelf Life
- Discharge and Charge Rates

Ragone Diagram

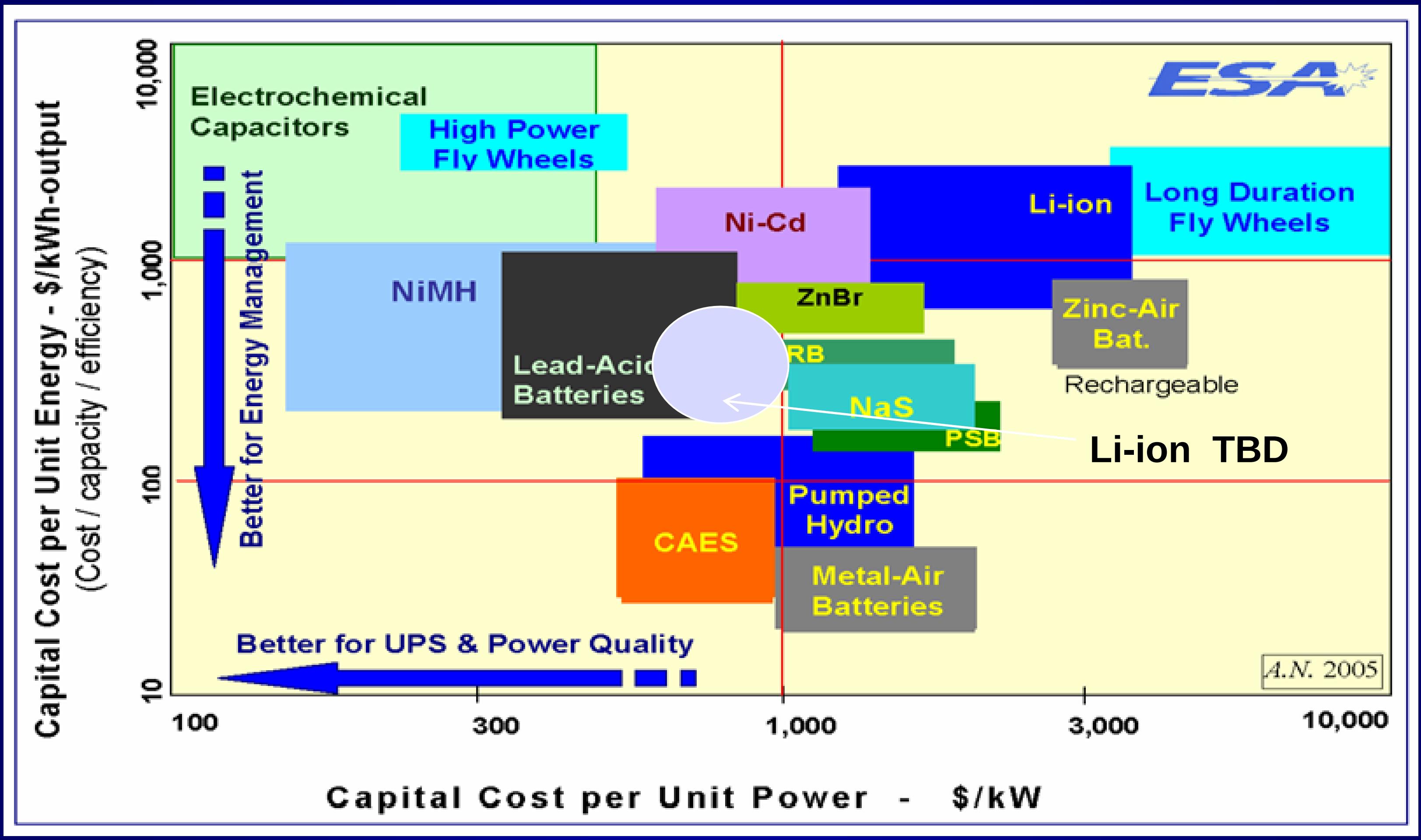


On-board electric energy storage (batteries, flywheels, super capacitors)



Battery type	Energy density Wh/kg	Power density W/kg	Service life in cycles / years
Lead-acid battery	30 – 50	150 – 300	300 –1,000 / 3 – 5
Nickel-metal hydride battery	60 – 80	200 – 300	>1,000 / >5
Lithium-ion battery	90 – 150	500 – >2,000	>2,000 / 5 – 10
Supercaps (double layer capac.)	3 – 5	2,000 – 10,000	1,000,000 / unlimited

Energy Storage Cost Points



Energy Density

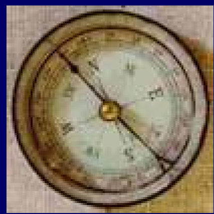
Nuclear	645,000,000
Automotive	8.10
Fuel Cell	1.62
Zinc Air Battery	1.33
Sodium Sulfur	0.77
Lithium Ion	0.54
Flywheel	0.5
NiMH	0.22
NiCd	0.14
Lead Acid	0.09
Redux	0.09
EC Capacitor	0.02
Spring	0.0003

For relative comparison only.

Advances in technology are changing capacities of these devices.

Possible Energy Storage Configurations

- Alignment
  - No Gap
  - Limited Gap
  - Full Storage
- Utilization of Regenerative Braking
- Power Quality & Voltage Sag Protection
- Efficiency



Putting it Together - Needs

- Alignment Definition
  - Terrain
  - Stops
  - Lengths between stations
  - Lengths of wireless operation
  - Ridership
- Vehicle Design
  - Storage
  - Regeneration
  - Efficiency
  - Maintenance

On-board Energy Storage Devices Receiving Significant Attention

- NiMH
- EC Capacitor
- Li-ion
- Hybrid – Battery / Capacitor
- Fuel Cell
- Flywheel

Practical Considerations

- Operations
- Maintenance
- Risk – Cost, Service, Experience, etc.
- Cost Investment / Payback
- Reliability
- Fit to Function

Implemention and Operations

T. R. Hickey, AICP

Vice Chair, APTA Streetcar and Heritage Trolley Subcommittee
Associate Vice President
Metropolitan Transit Authority of Harris County
Houston, Texas


METRO
EXISTING LINE
NEW LINES


SEPTA
Chartered
2324

Operator's Checklist

- Safe?
- Reliable?
- Affordable?
- Sustainable?

*Are the **RISKS** manageable?*

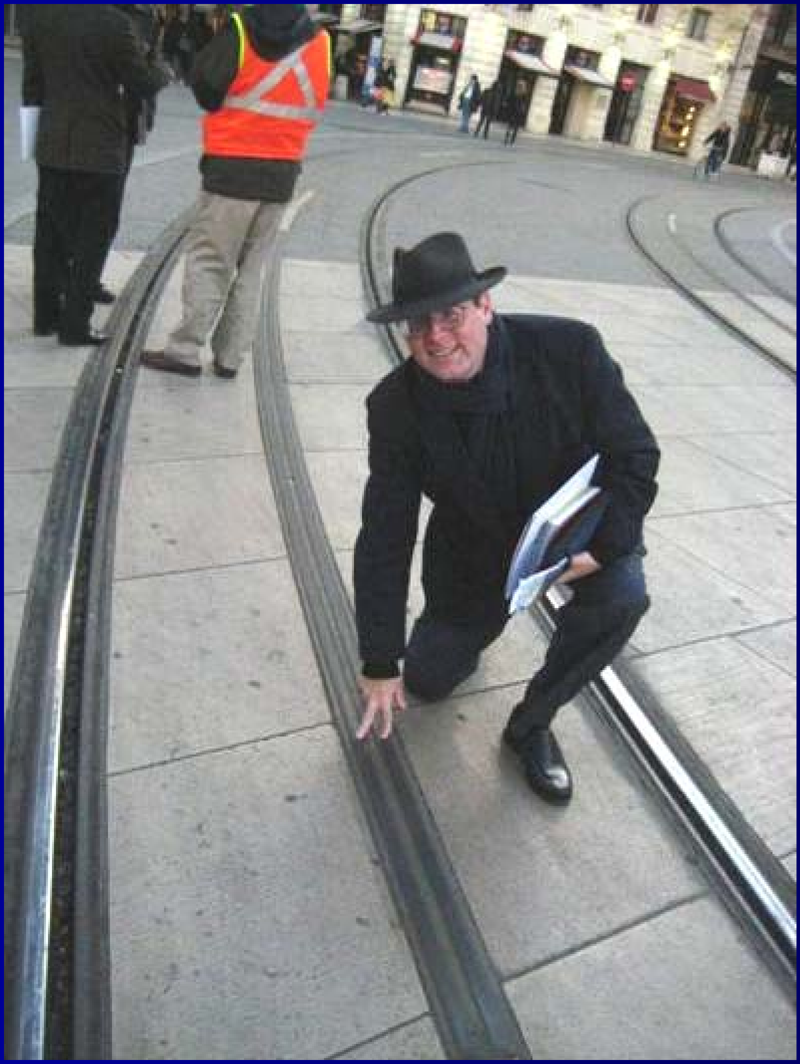
A Tale of Two Agencies…

Risk Management

- Begins with a Risk Management Plan
  - FTA Risk Assessment Process
    - Design/construction risks
      - What events may occur to the detriment of the project?
    - Probability
      - How likely is it that each event will occur?
    - Financial risk
      - What would it cost to mitigate/recover from an occurrence?
  - Defined and managed through a Risk Register

Risk Management

- Risk Management vs. Risk Avoidance
  - Assess your risks
  - Don't shy away from emergent technologies
    - But maintain realistic skepticism
    - Have a 'B' Plan ready



Practical Experience

James H. Graebner

Chair, APTA Streetcar and Heritage Trolley Subcommittee
President, Lomarado Group
Denver, Colorado

Summary

	Visual Impact	Capital Cost	O&M Cost	Proprietary Technology	Proven Reliability
POWER SUPPLY SYSTEMS					
Overhead Contact System	🟡	🟢	🟢	🟢	🟢
Underground Conduit System	🟢	🔴	🔴	🟢	🟢
Ground-Level Systems					
Contact	🟢	🔴	🔴	🔴	🟡
Contactless	🟢	🔴	? (yellow)	🔴	? (red)
On-Board Generation					
Internal Combustion	🟡	🟡	🟡	🟢	🟢
Fuel Cells	🟢	? (red)	? (red)	? (yellow)	? (red)
POWER STORAGE SYSTEMS					
Batteries	🟢	🟡	🟡	🟢	🟢
Capacitors	🟢	🟡	🟡	🟢	🟡
Flywheels	🟢	? (yellow)	? (yellow)	🟡	? (yellow)

🟢 No Issues
🟡 Minor Issues
🔴 Major Issues
? Unresolved

Thank you