City of Charlotte
Charlotte Streetcar Project

Streetcar Technology Assessment

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Submitted to:
City of Charlotte
Engineering & Property Management
600 East Fourth Street
Charlotte-Mecklenburg Government Center
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Executive Summary

Light rail transit (LRT) systems and streetcar systems have typically utilized an overhead catenary as a supply of electrical energy. Over the years, various municipalities have expressed interest in limiting the visual impact from overhead wires, preserving views of historic venues, avoiding low vertical clearance locations, and reducing impact to underground utilities from stray current. To meet this demand vehicle manufacturers have began developing a various array of technologies.

The purpose of this study is to identify and evaluate alternative methods of providing electrical energy from a wayside or on-board source to the vehicle's traction system.

The foundation of this study is the gathering of information regarding the state of the art in available energy systems for the propulsion of passenger rail cars. In order to obtain the most thorough information from manufacturers, an "Industry Day" session was held in Charlotte, to which an open invitation was issued to the industry to participate, present, and answer questions about their respective technologies.

A standard questionnaire was supplied to each respondent, with basic questions regarding their offered technology. This questionnaire is included in Appendix A.1 to this report.

Nine participants responded to the invitation, and presented their technologies on January 28 and 29, 2010 at the Charlotte/Mecklenburg Government Center. A synopsis of their technologies is presented in Table 1.

The Day #1 Industry Day meetings, held with select City of Charlotte staff and URS personnel, were beneficial in that the sessions allowed the manufacturers to provide a description of their respective firm, their manufacturing and testing capabilities, and their history in the transit industry in closed-door sessions. It allowed Team representatives to ask questions and become familiar with the various technologies that were presented. The Day #2 session on the 29th allowed the manufacturers to set up display booths which were open to other transit agencies and the general public.

In summary, there are two fundamentally different categories of alternative propulsion power being developed by the industry. First is an isolated conducting system located between the two running rails. The second is a system of energy storage on-board the vehicle to allow for non-catenary operation for limited distances.

In addition to the propulsion technologies being developed by the manufacturers, the additional technologies of hydrogen and diesel electric were examined. Table 2 reflects the findings of information provided by the various participating firms. The table illustrates the current status of each option, along with comments regarding operational concerns.

As these are emerging technologies, and further application design is required for specific design details for a system like Charlotte, it is recommended that these technologies be watched closely, and that specific cost information be sought as it becomes available.

Table 1		
Manufacturer	**Headquarters**	**Technology**
Alstom Transport	France	Segmented Third Rail, battery, or supercapacitors
AnsaldoBreda	Italy	"Tramwave" Third Rail, Supercapacitors
Bombardier	Germany	"Inductive" Third Rail, Supercapacitors
CAF / TrainElec	Spain	Battery / Capacitor recharge at stops
KinkiSharyo	Japan	Battery Storage
Proterra	Denver, Colorado	Battery or diesel hybrid on Bus
Siemens	Germany	Hybrid Capacitor Type
Skoda	Czech Republic	Fuel Cell, battery, capacitor or others
United Streetcar (OIW)	Portland, Oregon	Battery or Capacitor concept

Table 2			
Technology	**Manufacturer**	**Current Status**	**Comments**
Protected Third Rail	Alstom	In operation in Bordeaux, and Dubai.	Concern with operation in ice/snow with street salt. Not limited by distance.
Protected Third Rail	AnsaldoBreda	In operation in Milan, Italy.	Concern with operation in ice/snow with street salt. Not limited by distance.
Inductive Trackbed	Bombardier	Under test in Bautzen, Germany.	Not service proven. Not limited by distance. No exposed conductor.
On Board Super-Capacitor	CAF / TrainElec	In operation in Seville, Spain.	Limited distance between charges.
On Board Super-Capacitor	Bombardier	In operation in Manheim, Germany.	Limited distance between charges.
On Board Super-Capacitor	AnsaldoBreda	In operation in Florence, Italy.	Limited distance between charges.
On Board Super-Capacitor	Siemens	In operation in Lisbon, Portugal.	Limited distance between charges.
On Board Battery	Alstom	In operation in Nice, France	Limited distance between charges.
On Board Battery	KinkiSharyo	Under Test.	Limited distance between charges.
On Board Battery	Proterra	Bus Concept only.	Not service proven. Limited distance between charges.
On Board Battery	United Streetcar	Concept only.	Not service proven. Limited distance between charges.
Various	Skoda	Concept only.	Not service proven. Limited distance between charges.
On Board Battery	Kawasaki	Under Test.	Not service proven. Limited distance between charges.
Hydrogen	n.a.	In R&D.	Not service proven.
Diesel-Electric	n.a.	Available	Proven technology that has never been applied to streetcar operation. Industry not moving in this direction.

1.0 INTRODUCTION

The City of Charlotte is currently in the preliminary engineering phase of the Charlotte Streetcar Project. The initial streetcar line will provide an additional transportation option in and around Uptown Charlotte and catalyze development along the proposed route.

Parts of the proposed streetcar route will travel under bridges that do not have recommended vertical clearance to allow for installation of an overhead catenary system. Additionally, portions of the alignment pass through areas of high visual significance where the introduction of overhead wires may be undesirable.

URS has been requested to investigate alternative energy sources for the streetcars that would allow for the vehicle to move through select areas without the use of the overhead catenary wire.

To date, streetcar propulsion and on-board auxiliary systems in the United States have typically been powered by direct current electrical energy. This energy is typically transferred to the vehicle from the wayside source via an Overhead Contact System (OCS). OCS typically consist of vertical support poles on both sides of the trackway, suspending a grid of overhead wires and insulators. Directly above the centerline of the trackway is a main conductor, which runs the length of the trackway system to provide power to the vehicle. Electrical energy is transferred from the overhead wire to the vehicle by a roof-mounted pantograph, which is spring loaded in an upward direction to maintain contact with the overhead wire. Due to the amount of aerial infrastructure involved with this system, some may consider the OCS model to be visually obtrusive.

Several new technology developments are yielding alternatives to providing energy to a Streetcar via overhead wires. These include inductive energy transfer, on-board fuels such as hydrogen, hydrogen fuel cells, diesel-electric hybrids and combined battery and capacitor systems.

Each of these technologies has been initiated by individual manufacturers, and as such, each technology will be considered as “proprietary”, in that the respective design features of that technology are protected by patent, and are available only from that manufacturer.

As part of the data gathering effort of this project, manufacturers were invited to attend an “Industry Day” in Charlotte to present their technologies and levels of development to the City.

This report will review each of the technologies, with a summary of the benefits, drawbacks, and levels of risk for each. A discussion on cost is also included in Section 5, Evaluation, of this report.

2.0 SCOPE OF WORK AND GOALS

This report presents the results of an investigation and evaluation of power distribution and energy storage technologies applicable to Mass Transit Vehicles. Specifically, this investigation focused on the utilization of energy sources that would preclude the use of an overhead catenary for all or part of the proposed Charlotte streetcar route.

Technologies were identified during the course of the investigation through research of periodicals, manufacturer's data, and industry publications.

Evaluation criteria were developed that apply to the mass transit industry, to include those factors that affect performance, cost, reliability, and safety.

An "Industry Day" was held in Charlotte, where manufacturers of available technologies were invited to present their technical approach to non-catenary operation. Nine firms were in attendance, with each describing their technology and a brief synopsis of their organization. This Industry Day allowed for the gathering of invaluable information on each manufacturer's system. The information gathered is included in this report and attached in the appendix.

The goal of this data gathering effort, analysis, and report is to provide to the City of Charlotte a comprehensive evaluation of state-of-the-art non-catenary power systems for streetcar propulsion. As there are currently several emerging technologies, it is recommended that, once the City draws near to the issuance of a solicitation for a system, the most current data for those firms be revisited, and re-evaluated against the criteria identified herein.

3.0 RESEARCH

The technologies associated with the transfer of power from the wayside of a passenger rail system to the vehicles are emerging, and being developed by a host of manufacturers in the passenger rail vehicle market. The following technologies were the primary focus for this report:

- Third rail technology, both inductive and physical contact, uses an embedded rail between the running rails for transfer of energy. The third rail is energized only when the vehicle passes over that segment of rail. Energy is then transferred by either a physical contact with the rail or by means of induction. When the vehicle is not present, then that rail segment is not energized.
- Battery and/or capacitor are onboard energy storage systems that deliver power to the vehicle. Once the battery or capacitor is depleted, it must be recharged from a power source such as OCS, regenerative braking, other wayside power supply or any combination thereof.
- On-board Fuel Systems such as Hydrogen fuel cells, hydrogen internal combustion engines, and clean diesel-electric generator sets were investigated. The hydrogen based systems have not been advanced to a point where they can be applied to a transit vehicle for commercial application. Fuel cell technology continues to be developed along with the infrastructure required for hydrogen fuel cells including storage tanks and pumping equipment for refueling the vehicles. Diesel-electric generator sets have been used in various applications in the United States and abroad, however the industry is moving away from fossil fuel based systems.

Information associated with each of these technologies had been identified as part of ongoing research to maintain an awareness of the state of the art.

For this report, further investigation into each of these technologies was performed using industry periodicals, published manufacturer information, the responses to the questionnaires, and lastly, information gathered during the Industry Day presentations.

As the technologies are emerging, manufacturers provide only high level information on their respective systems. Specific design details associated with each system are not available, as a level of application design must be performed for each technology in order to properly estimate factors such as cost, weight, on-board space requirements, etc.

Investigations into each of the technologies also revealed that the systems are at various stages of development, some more mature and approaching a stage for commercial application, and others less mature, and not currently ready for commercial offer.

Given the data available, more qualitative evaluations of each technology have been performed, and are presented in the following sections of this report.

4.0 INDUSTRY DAY

In this section, a general description of each technology presented at Industry Day and its main features is provided, along with a high level description of interfaces, structural impacts, any known economic factors, and existing applications. Manufacturers are presented in alphabetical order.

Some of the manufacturers are world-wide turnkey systems providers, with broad experience in all facets of transit system design, development, manufacture, installation, commissioning, operations, and maintenance.

Other manufacturers are emerging car-builders, whose development of streetcars is ongoing.

It should be noted that proponents of emerging technologies without specific experience and service-proven equipment in the streetcar arena were also contacted.

Manufacturers participating in the Industry Day included:

Table 3

Manufacturer	Headquarters	Technology
Alstom Transport	France	Segmented Third Rail or battery / super capacitors
AnsaldoBreda	Italy	"Tramwave" Third Rail, Supercapacitors
Bombardier	Germany	"Inductive" Third Rail, Supercapacitors
CAF / TrainElec	Spain	Capacitor recharge at stops
KinkiSharyo	Japan	Battery Storage
Proterra	Denver, Colorado	Battery or diesel hybrid on Bus
Siemens	Germany	Hybrid Capacitor Type
Skoda	Czech Republic	Fuel Cell, battery, capacitor or others
United Streetcar (OIW)	Portland, Oregon	Battery or Capacitor concept

*No manufacturer specifically presented hydrogen fuel cells as a power source

4.1 ALSTOM TRANSPORT

Alstom Transport develops and markets a complete range of systems, equipment, and service in the railway industry. The company provides high-speed trains, metros, and tramways, and is among the leaders for electrical and diesel trains, information systems, traction systems, power supply systems and track work.

Alstom designs, produces and installs infrastructure for the rail network to upgrade safety and performance of existing networks, or as part of new turnkey solutions. This includes information solutions, electrification, communication systems, track laying, station utilities, workshops, and depots.

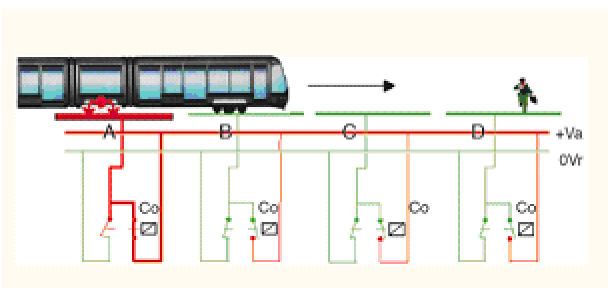
The company provides light rail systems including tramways with or without electric overhead lines, metro systems and air-rail links (traditional and automatic).

Renovations with technological upgrades, short- or long-term maintenance of any type or brand of mass transit rail vehicle, and spare parts service are also offered.

Alstom has developed two non-catenary based transit vehicle propulsion systems; one utilizing batteries and super capacitors and the other utilizing an embedded "third rail".

Alstom is currently implementing battery technology in Nice, France, and supercapacitor technology in Paris, France.

Alstom has developed a power distribution technology which utilizes a "third rail" embedded in the trackslab between the running rails. This third rail is controlled in a manner such that only that segment of third rail below the operating vehicle is energized. This control includes switching devices located at roughly 22 meter (75 feet) intervals along the trackway. The technology is developed in full, and is in operation in Europe and the Middle East. Concern exists with the potential for stray currents where the roadway is wet or wet with a salt solution for snow clearing. This solution is feasible for the full elimination of a pantograph and overhead catenary.



Alstom Segmented Power Rail

4.2 ANSALDOBREDA

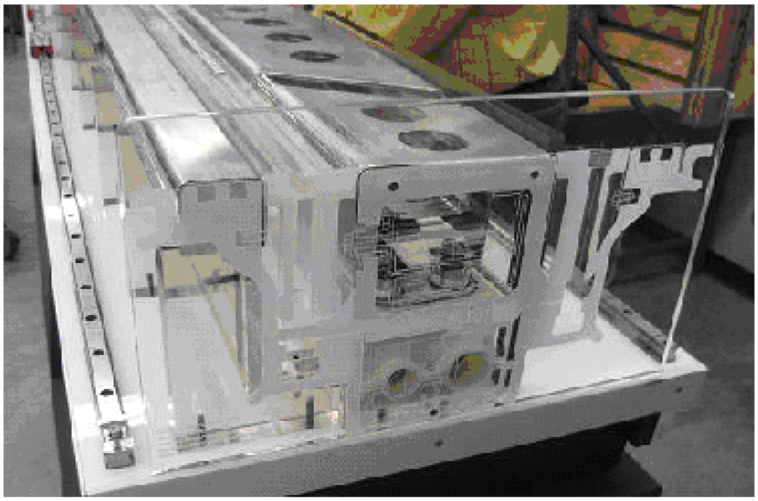
AnsaldoBreda was formed in 2001 by the merger of Ansaldo Trasporti and Breda Costruzioni Ferroviarie and is owned by Finmeccanica S.p.A.

AnsaldoBreda manufactures railway cars, trams, and trains for commuter rail, high-speed rail, and main lines. Their Sirio is a low-floor tram model used in cities throughout Europe.

AnsaldoBreda offers two technologies for the elimination or reduction of the OCS system.

AnsaldoBreda has developed a power distribution technology, TramWave, which utilizes a "third rail" embedded in the trackwork between the running rails. This third rail includes a contact feature in the rail, such that only that segment of third rail below the operating vehicle is energized. This is achieved with a flexible contact ribbon within the third rail. This ribbon is magnetically attracted to the conducting surface of the third rail as the vehicle passes over the rail. The technology is developed in full, and is in operation in Europe. Concern exists with the potential for stray currents where the roadway is wet or wet with a salt solution for snow clearing. Their Sirio car combined with TramWave technology is a feasible solution for the full elimination of a pantograph and overhead catenary.

AnsaldoBreda has also utilized a supercapacitor system for the bridging of rail gaps. This system would provide for operation between charging stations, thus eliminating the need for overhead catenary in distances limited by the on-board storage capacity of the super-capacitors.



AnsaldoBreda "TramWave"

4.3 BOMBARDIER

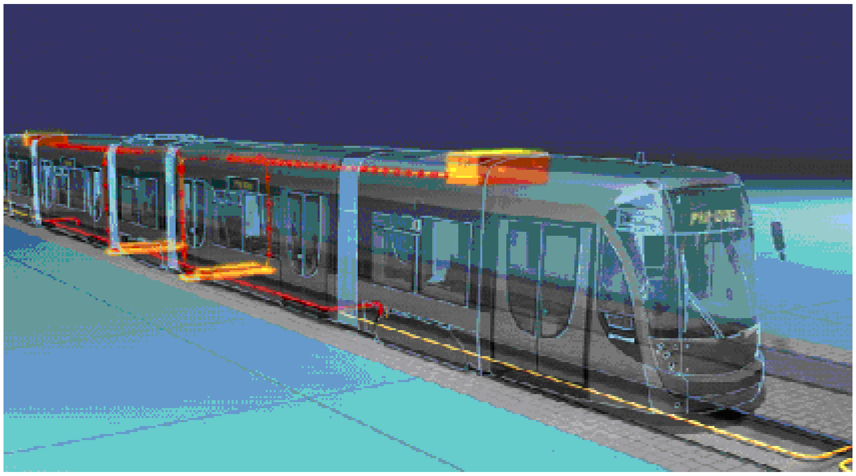
Bombardier Transportation is the rail equipment division of Bombardier Inc. Bombardier Transportation is one of the world's largest companies in the rail equipment manufacturing and servicing industry. Its headquarters are in Berlin, Germany.

Their wide range of products includes passenger rail vehicles, locomotives, bogies, propulsion, and controls. They also provide rail control solutions and build total transit systems.

Bombardier offers two different technologies for the elimination or reduction of the Overhead Catenary System.

The first technology which has been developed is a power distribution technology based upon the configuration of a "split transformer", imparting energy to the vehicle from the trackway using inductive magnetic fields. Within the trackway, and between the running rails, is a conductive loop, which when activated by a passing vehicle, is energized, creating a magnetic field beneath that vehicle. As the vehicle traverses the magnetic field, an on-board receptor converts that magnetic field into electrical energy to power on board propulsion and auxiliary systems. Their Primove technology is developed in full, and is undergoing test in Bautzen, Germany. This technology fully insulates the ground borne inductive loop from the running area, and thus will not present the risk of stray currents. This solution is feasible for the full elimination of a pantograph and overhead catenary.

Bombardier has also utilized a supercapacitor system for the bridging of rail gaps. This system would provide for operation between charging stations, thus eliminating the need for overhead catenary in distinct short distances.


Bombardier Primove Technology

4.4 CAF

Construcciones y Auxiliar de Ferrocarriles (CAF) is a rail equipment manufacturer based in Spain. Equipment manufactured by CAF includes light rail vehicles (LRVs), rapid transit trains, railroad cars, and locomotives.

CAF has manufactured rail cars for the Washington Metro, Port Authority Transit in Pittsburgh, Pennsylvania, and Sacramento Regional Transit. CAF also manufactures vehicles for light rail/tramway systems. Currently in production are 27 vehicles for the new Edinburgh Trams system in Scotland.

CAF has proposed an on-board solution to the elimination of OCS technology which employs a set of high energy capacitors located on the roof of the vehicle. These capacitors hold sufficient electrical energy to power the vehicle for approximately 1 mile. When capacitors are discharged to the point where recharge is required, the vehicle will berth in a station, and make contact with a stationary DC power source to re-charge. In addition, if an OCS is provided, capacitors may recharge while running in contact with the OCS. Recharge periods are estimated by CAF to be approximately 20 seconds. This technology is well developed, and is in use in Seville, Spain to address the issue of power loss in rail gaps.

CAF Streetcar

4.5 KINKISHARYO

The KinkiSharyo Co., Ltd. is an Osaka, Japan-based manufacturer of railroad vehicles. It is an affiliate company of Kintetsu Corporation. In business since 1920 as Tanaka Rolling Stock Works, the company was renamed as The KinkiSharyo Co., Ltd in 1945. Kinki Sharyo has a long history of providing reliable light rail vehicles in North America, with major installations in Seattle, Phoenix, Dallas, Boston, New Jersey, and Portland.

KinkiSharyo has also proposed an on-board solution to the elimination of OCS technology. The KinkiSharyo system includes a set of on-board batteries located at various locations on the vehicle. These batteries are stated to hold sufficient electrical energy to power the vehicle for approximately 3 miles. When batteries are discharged to the point where recharge is required, the vehicle will either berth in a station, or raise a pantograph and make contact with a stationary DC power source to re-charge. This technology is well developed, but is not currently operating in revenue service. Also, the 3-mile range has not yet been achieved in service.

Kinkisharyo Streetcar

4.6 PROTERRA

Proterra is a manufacturer of bus and truck drive systems, including battery storage, rapid charge battery systems, composites, and bus chassis.

Proterra has proposed an on-board battery solution to the elimination of OCS technology. The proposed battery system has not been applied to a rail vehicle, and no application details have been developed. It is noted that this type of systems integration is critical to the proper design and manufacture of a propulsion system.

Proterra Bus

4.7 SIEMENS

Siemens Transportation Systems is a division of Siemens AG, and provides products including automation and power systems, rolling stock for mass-transit, regional and mainline services, turnkey systems and integrated services, railway signaling and control systems, and railway electrification.

Siemens products include electric and diesel multiple units, electric locomotives, Metro vehicles, Low Floor LRVs, and Trams.

Siemens has proposed an on-board solution to the elimination of OCS technology which employs a set of high energy capacitors located on the roof of the vehicle. These capacitors hold sufficient electrical energy to power the vehicle for approximately 1 mile. When capacitors are discharged to the point where recharge is required, the vehicle will berth in a station, and make contact with a stationary DC power source to re-charge, which is estimated to require a recharge period of between 30 and 60 seconds. This technology is well developed, and is in use by propulsion suppliers to address the issue of power loss in rail gaps.

Siemens Streetcar

4.8 ŠKODA

ŠKODA Transportation, is a European manufacturer of rail vehicles for municipal and suburban public transportation located in Plzen, Czech Republic, and has introduced the prototype for its new ŠKODA ForCity trams. ŠKODA Transportation will supply Prague's public transportation company with a total of 250 three-car low-floor ŠKODA ForCity trams by 2017.

Skoda generally presented their vehicle manufacturing capability, proposing a variety of possible propulsion technologies including any combination of on-board hydrogen fuel cells, batteries, capacitors, clean diesel and conventional OCS.. This configuration has not been applied to a rail vehicle, and has not been developed fully. Skoda also indicated that they can integrate other manufacturer's propulsion systems onto their vehicle, however no applications of this have been produced by Skoda at this time. It is noted that this type of systems integration is critical to the proper design and manufacture of a propulsion system.


Skoda Streetcar in Portland Oregon

4.9 UNITED STREETCAR

United Streetcar, LLC, is a wholly owned subsidiary of Oregon Iron Works, Inc. (OIW) based in Portland, Oregon. OIW is a specialized fabrication and manufacturing company founded in Oregon in 1944.

United Streetcar has extensive innovative manufacturing and integration experience from its parent company, Oregon Iron Works, Inc., which has history and success in both commercial and government contract work. Streetcar fabrication aligns with OIW's long term proven manufacturing capability as well as the experience of OIW's team of personnel.

United Streetcar is currently developing a technology relationship with Rockwell to provide on-board electrical propulsion. At present, this design is a standard 3 phase AC Drive technology.

United Streetcar also proposed an on-board solution to the elimination of OCS technology. The United Streetcar system, which is being developed with their partner Rockwell, includes a set of on-board batteries and/or capacitors located at various locations on the vehicle. With application design yet to be performed, the locations and capacity of these devices is unknown. These energy storage devices are planned to hold sufficient electrical energy to power the vehicle for an undetermined period. Development is in progress, and product offering is expected in 2 to 3 years.

United Streetcar

4.10 KAWASAKI HEAVY INDUSTRIES

Kawasaki Heavy Industries, a major Japanese heavy machinery manufacturer, produces the Gigacell, the company's nickel metal-hydride battery for vehicles. The SWIMO light rail vehicle can be fitted with this battery system for non-catenary operation. Mounting the Gigacell on the tram car provided by Chikuho Electric Railroad in Fukuoka Prefecture, the company has tested the system with successful results.

Kawasaki has not offered their own propulsion system for sale in the United States, utilizing a plant in Yonkers, New York for car assembly purposes only. Further evaluation of the specific application design parameters of this battery system will need to be performed to confirm the system's operating range.

Streetcar SWIMO powered by both overhead lines and nickel metal-hydride battery

5.0 EVALUATION

The market for railcar technology and technology development is in continuous change and improvement. As electrical and electronics industry products are developed which could be applied to the transit market, carbuilders evaluate the technology, and develop applications to various rail system vehicles.

A modern transit system depends upon proven, reliable equipment for successful and cost effective operation.

Equipment that is not service proven can result in costly failures, train service delays, traffic disruptions, retrofits, equipment damage, or even employee or passenger injury.

Specifications for the design, manufacture, and test of mass transit equipment have been in evolution in parallel with technology developments. Materials, processes, electrical components, and software are in continual change, and take a form today unheard of in the 1950s, for example.

To assure that the issues above are avoided, it is recommended that the City of Charlotte follow a process of risk identification and avoidance. This includes an evaluation of the feasibility of a technology at the conceptual stage of a project.

A thorough risk assessment and mitigation program will then continue through specification development, the procurement process, the design review process, and finally test and commissioning.

5.1 EVALUATION CRITERIA

The market for railcar technology and technology development is in continuous change and improvement. While the transit industry holds a conservative approach to the implementation of new technologies, ongoing review of technology is important to improving reliability and reducing operation and maintenance cost.

Ten manufacturers (9 present at interviews) of emerging technologies were evaluated. They are categorized herein by manufacturer, in alphabetical order. While some similarities exist with the technologies presented by each manufacturer, there are differences including the types of batteries or capacitors utilized, the unique design of the system, and the level or degree of development.

Onboard and wayside systems contain a wide variety of elements, including electrical components, mechanical parts, software, wiring, enclosures, and structural assemblies.

A system to transfer power from the wayside to a vehicle, or to provide stored energy on-board a vehicle, also includes a wide range of elements.

This study focused strictly on the elements of the proposed systems to provide energy to propel the transit vehicle (Streetcar). These criteria were categorized as “service proven”, maintenance, safety, risk, and cost. Evaluation criteria include:

- Capability to Travel Distance – Battery and capacitor technologies are limited in that the vehicle must recharge the batteries/capacitors at regular intervals. The “third rail” technologies are not limited in this fashion.
- Time for Regeneration of Capacitors / Batteries – The technologies presented for battery / capacitor use must be recharged at intervals defined by the capacity of the system. It is noted that where this time exceeds the normal station dwell time, the longer recharge times will inhibit the overall passenger carrying capacity of the system. Recharge times at stops may be reduced by re-introducing limited OCS in advance of the recharge stations.
- Performance (speed, acceleration, or deceleration) – Both sets of power transmission technology present a limitation in the ability for the system to achieve a high speed. The battery/capacitor systems limit speed, as higher speeds and accelerations require greater energy. The “third rail” systems are speed limiting in that their segmented power blocks have a fixed switching speed. Generally, the speed limitations for these systems are within the normal operating parameters for a streetcar running in mixed traffic.
- Environmental Considerations (ice, snow) – The “third rail” systems which include exposed conductor surfaces, albeit immediately beneath the vehicle, may be susceptible to weather conditions of rain, ice, and/or snow. Particularly where wet conditions are accompanied by salt for ice clearing, the concern exists for stray currents from beneath the vehicle to nearby pedestrians.
- Limitations or Impacts on the Physical Infrastructure – All of the technologies evaluated will have some impact upon the physical infrastructure of the system. The “third rail” technologies require additional excavation for placement of underground switching components and the respective cross section of the technology. The battery / capacitor technologies require recharging power stations at locations along the system’s route. These impacts affect installation cost and later, maintenance. The battery – capacitor technology may allow elimination of part of the OCS poles and wire, however the limits of the elimination are unknown at this time and it is likely that adjacent power charging stations would need to be connected via an additional traction power ductbank.
- Level of Development – A portion of the technologies reviewed are currently in demonstration test, or in operation in a single location for evaluation purposes. Other technologies are in hardware development, and others are conceptual as applied to a rail vehicle.

- Overall Cost Ramifications – With the lack of application engineering associated with each of these technologies which would allow the respective manufacturer to confidently develop cost data, subjective cost evaluations have been performed. These subjective evaluations, made in comparison to an Overhead Catenary System baseline include consideration of additional equipment needed for the technology, such as on-board batteries, underground electrical switching boxes, added effort for safety certification, and a contingency for unknowns and remaining research and development. Note that cost comparisons are strictly judgment based estimates with no real world validation, and compare the cost of an overhead catenary system to the hypothetical cost of an alternative system. High cost implication is defined as a 100% or higher cost premium over OCS, medium cost implication is defined as between 50% and 100% premium, and low cost implication is defined as between 10% and 50% premium.
- Overall Risk – Along with the subjective cost evaluation, a subjective evaluation of risk has been performed. Elements of risk include level of technology development and safety.

These evaluation criteria were presented in the form of questions to manufacturers at Industry Day, and their responses were then evaluated for feasibility for inclusion in this report.

5.2 EVALUATION RESULTS

The results of the evaluation are presented in Table 4. It is noted that as several manufacturers offer essentially the same technical approach, the comparison is based on differing technologies only.

Table 4						
Technology						
	Segmented Third Rail	**Tramwave Third Rail**	**Inductive Third Rail**	**On-Board Capacitor**	**On-Board Battery**	**Hydrogen**
Travel Distance Limitation	Not limited	Not limited	Not limited	Up to 1 mile	Up to 3 miles	Limited only by fuel storage capacity.
Regeneration Time	n.a.	n.a.	n.a.	30 – 60 sec.	6 min	Not Known
Speed / Performance	60 mph	Unknown	42 mph	Tradeoff with capacitor weight	Tradeoff with battery weight	Not Known
Environmental Considerations	Concern with rain, salt slush	Concern with rain, salt slush	None	None	None	None
Infrastructure Impact	Control box installed in-ground every 75'.	12" x 12" cross section between rails	Control boxes installed in-ground.	Charging equipment needed at stations	Charging equipment needed at stations	Hydrogen storage and filling systems needed, extents of which are not known.
Level of Development	In operation in Bordeaux	In operation in Florence	Testing in Bautzen, Germany	Commercial operation, multiple cities of Seville, Lisbon, Manheim, and others	Commercial application in Nice	Concept
Overall Cost Ramifications	Medium	Medium	Medium	Low	Low	High
Risk (1 = high, 5 = low)	4	4	5	4	3	1

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6.0 CONCLUSION

The market for railcar technology and technology development is in continuous change and improvement. While the transit industry holds a conservative approach to the implementation of new technologies, ongoing review of technology is important to improving reliability and reducing operation and maintenance costs.

Advancements in power distribution technologies are being made by virtually all major railcar builders, with some having developed technologies to the point of having systems in revenue operation, while others are only in early stages of development.

Generally the technology that is the furthest along in development, by the most manufacturers is the battery / capacitor. Both of these involve on-board storage devices to capture and hold energy for use in areas where there is no OCS available. Regenerative energy can also be stored in this system from the application of braking. As such, the power requirements of the vehicle must be identified, grades traversed analyzed, and vehicle weight known. This level of systems design will allow the application engineers for the respective manufacturer to calculate the amount of energy storage required, and thus the size and weight of the energy storage device, be it battery or capacitor.

A system traversing a grade, with a heavy streetcar, and a high passenger load, and needing to travel a relatively long distance will require greater storage capacity than a system traversing level track with lower vehicle weight. Additionally, a system with severe environmental constraints that require heavy use of heating and cooling would add to the needed storage capacity. Consequently, the recharge periods for the higher energy storage levels will be greater than those of lower levels of energy storage.

Further, the application design of the on-board equipment sets for battery power and capacitor power storage has not been performed for the specific Charlotte application. As such, any impact on underfloor or rooftop equipment layout has not been performed, nor is any impact on interior packaging such as the number of seats impacted been identified. These application details have yet to be identified for any route alignments for the City of Charlotte.

Embedded “third rail” system appear to be significantly far along in development however they are more capital intensive, have higher operation and maintenance costs and require more substantial safety certification. Additional concerns exist regarding the proprietary nature of the technology and the potential to become dependent on a single supplier.

Overall, the implementation of a technology to replace an overhead contact system in whole or in part will represent an increase in the cost of construction and operation of a streetcar system, albeit some technologies have promise to be nearly cost neutral; and may someday even prove more cost effective.

7.0 RECOMMENDATION

The data gathered during the investigations associated with this report along with the information obtained during Industry Day are sufficient to support the conclusion herein.

As such, it is recommended that the City further investigate the use of battery and/or capacitor type propulsion for any new streetcar vehicle procurements. Additionally, the City should partner with peer cities that are also considering this technology to perhaps enter into a joint procurement.

In the instance where the City decides to utilize the existing Gomaco Trolley's or exercise a vehicle option from another transit property, the City should continue with the conventional OCS design, while monitoring the progress of the development of battery and capacitor systems for application in future phases. It is noted that the battery / capacitor systems can subsequently be utilized for limited distance application to address low clearance obstructions, areas of high visual significance and capturing regenerative energy resulting in operation savings.

With the battery and capacitor type of system, portions of the line could utilize OCS while others do not. Initial segments of the system may be better candidates to use conventional OCS technology, while subsequent extensions may be better suited to implement wireless zones.

A technology procurement must be systems based, with focus given to identifying the alternative power distribution as an integrated part of the Streetcar installation, with all vehicle, wayside, facilities, and support costs and work areas identified.

Such a procurement could be managed as a "best value" for service proven equipment. Specifications for such a procurement must be performance based in order to allow the greatest range of feasible technologies to participate. For any immediate procurements for the Charlotte Streetcar Project, it is recommended that conventional OCS technology be used.

A APPENDICES

This section includes the questionnaire, along with reference materials provided by the manufacturers during Industry Day.

A.1 QUESTIONNAIRE

City of Charlotte
Alternative Technology Questionnaire

1	**Electrical/Mechanical/Civil**
a	Is the system limited by distance in any way?
b	What are the power requirements for wayside power?
c	How does the power consumption of the system compare to traditional catenary?
d	Does the system transition between catenary and non-catenary operationally? If so, how?
e	For systems utilizing battery/capacitor elements, what it recharge rate?
f	Are there limitations to vehicle performance (speed, acceleration, or deceleration)?
g	Does the system have regeneration capabilities?
h	How is stray grounding current addressed?
i	Has the technology been applied in a manner similar to what would be utilized in Charlotte? If so, where?
j	Describe limitations or impacts on the physical infrastructure.
k	How soon will the technology be available for revenue application?
2	**Maintenance**
a	Is real maintenance cost data available for the technology? If not, detailed estimates will need to be provided.
b	Has an LCC Analysis been performed for the technology? Has it been benchmarked with service history?
c	What are the energy, consumable, and manpower operating costs for the technology
d	Are there plans for parts support? Is ongoing manufacturing of anticipated replacement components planned?
e	Are there plans for installation and overall service support?
3	**Safety / Risk**
a	Is the technology service proven? Has it been utilized in revenue operation? For how long? Are there reliability figures available for the technology? If not, what measurable characteristics can be used to evaluate its serviceability?
b	Has the technology been utilized in an environment of sun/rain/freezing as will be experienced in Charlotte?
c	Has a safety study been performed? Is there operational safety data available for the public and for operators/maintainers?
d	An overall risk evaluation will be needed for the proposed technology.
4	**Capital Cost**
a	Given an estimate model, what is the capital cost for all elements of the system installation, both carborne and wayside? Are there real examples of real installations that can support the estimates?
b	How mature is the system? What are the vulnerabilities to retrofitting due to design change?

A.2 INDUSTRY DAY SUMMARY TABLE

City of Charlotte
Alternative Power Technology Summary

The table below presents a summary of the technologies that were reviewed during the "Industry Day" at Charlotte Mecklenburg Government Center on January 28, 29, 2010. Evaluations are preliminary, and intended to illustrate the overall level of feasibility for each proposed technology.

Manufacturer:	Alstom	Alstom	Ansaldo-Breda	Bombardier	Bombardier	
Description:	Segmented Third Rail	Battery Storage	"Tramwave" Third Rail	Inductive Loop	Capacitor Storage	
Energy Source Location	Between Rails	Vehicle Roof	Between Rails	Between Rails	Vehicle Roof	
Range	Not applicable	1,500 feet	Not applicable	Not applicable	Not given	
Recharge	Not applicable	Not given	Not applicable	Not applicable	Not given	
Proven System	Yes	Yes	Yes	In Testing	Yes	
Rail Experience	Yes	Yes	Yes	In Testing	Yes	
Risk (1 - 10, 1 is low risk)	2	3	3	3	2	
Est. Cost (1 = OCS)	1.1	1.1	1.1	1.1	1.1	

Manufacturer:	CAF / TrainElec	KinkiSharyo	Proterra	Siemens	Skoda	United Streetcar
Description:	Capacitor Storage	Battery Storage	Battery on Bus	Hybrid - Capacitor	Fuel Cell, Battery, & Cap	Battery or Capacitor est.
Energy Source Location	Vehicle Roof	On Car	In development	Vehicle Roof	Various (bus exp.)	On Car
Range	1.1 miles	3 miles	In development	1.1 miles	Not available	Goal of 1 mile
Recharge	20 seconds	Six minutes	6 – 10 min	30 to 60 seconds	Not available	Not available
Proven System	Yes	No	No	Partial	Bus, but not rail	No
Rail Experience	Yes	No	No	Yes	Not developed	No
Risk (1 - 10, 1 is low risk)	3	3	8	3	9	4
Est. Cost (1 = OCS)	1+	1+	Unknown	1+	Unknown	1+