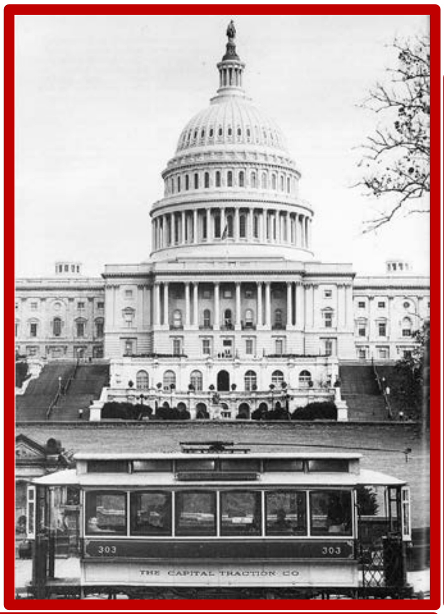
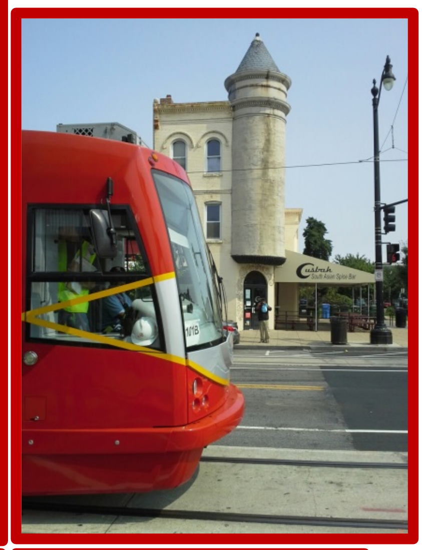
Comprehensive Assessment

On Streetcar Propulsion Technology






Prepared for

Council of the District of Columbia

Prepared by

District Department of Transportation

July 31, 2014

Executive Summary

This **Comprehensive Assessment on Streetcar Propulsion Technology** is a report prepared for the District Department of Transportation in order to assess the feasibility of various non-aerial motive power technologies for streetcar propulsion in the District of Columbia.

It is important to note that there is no system, national or international, which relies completely on non-aerial motive power technologies for streetcar propulsion. Used in combination with catenary powered systems the non-aerial motive power (off-wire) systems propel the streetcar for short distances up to one mile. These off-wire systems are fairly new, have limited applications, and the technologies continue to evolve. With limited applications there are concerns about safety and reliability of the system.

The available off-wire technologies fall into one of the two categories:

- On-Board Energy Storage Systems
- Ground Level Power Systems

Based on initial research completed in 2011 and additional research conducted in 2013-14, on behalf of DDOT, HDR has analyzed and consolidated the available off-wire technologies with pros and cons of each with emphasis on their applicability in the DC environment. The analysis addressed the rough-order-of-magnitude costs and feasibility of installing a new off-wire system as well as the rough-order-of-magnitude costs and feasibility of converting a catenary-based system to an off-wire system.

The *Summary Assessment on Streetcar Propulsion Technology,* attached as Section A, represents the core findings of this report and responds to the questions posed by the Transportation Infrastructure Amendment Act of 2010 (TIAA) regarding DC Streetcar:

1. Identify advances in propulsion technology and better understand the “state of the art”

2. Discuss the feasibility of converting to non-aerial motive power where overhead wires have been installed.

3. Discuss the feasibility of converting to non-aerial motive power for proposed (future planned) streetcar segments.

4. Recommended amendments to the TIAA, including a potential sunset date.

The state of off-wire (or wireless) motive power or propulsion systems technology for streetcars is evolving, but not yet mature. Two main categories of solutions exist. One of these categories, Ground Level Power Supply Systems (GLPSS), generally involves proprietary systems that have limited proven applications and that may have higher short and long term costs. The second category, On-Board Energy Storage Systems (OESS), generally focuses on battery and super capacitor technologies. These technologies are also limited in their proven applications, having only been implemented in dedicated rights-of-way, in relatively flat areas, over limited distances and in favorable climates. These technologies would face challenges operating in the District's more difficult environment (topography, weather, traffic conditions).

In general, the existing level of off-wire propulsion technology is not seen as mature enough to fully achieve the District's ultimate goal of a completely off-wire system in the near term. As these technologies continue to evolve, the District's goal would be achievable. Therefore, it is anticipated that the District will gradually implement an off-wire system. In the near term, proven overhead contact system (OCS)-based technologies will form the basis of the system, with limited application of off-wire technologies in the most sensitive areas to the extent possible. As technologies advance, the amount of off-wire operations will be gradually increased.

In addition to the *Summary Assessment on Streetcar Propulsion Technology,* attached as Section A, additional supporting information is presented in Sections B-D

Attachments include the following:

1. Section A: Summary Assessment on Streetcar Technology, July 2014 – This report summarizes DDOT's findings regarding off-wire streetcar technologies and responds directly to the requirements of the Transportation Infrastructure Amendment Act of 2010.
2. Section B: Wireless Operation in the District of Columbia, October 2011 – This summarizes a previous research effort conducted under DDOT's direction.
3. Section C: Wireless Streetcar Applications for the District of Columbia Presentation, March, 2013 – A summary presentation provided to the Mayor's Streetcar Finance and Governance Task Force.
4. Section D: Alternatives Analysis for Premium Transit Service PROPULSION STUDY, September 2013 appendices:
   a) Appendix A – Data Collection Module
   b) Appendix B – Technical / Informative Sessions with Car Builders

Section D incorporates several other studies and reviews from various sources including consulting firms, manufacturers' marketing materials, research papers and presentations from Transportation Research Board (TRB) and American Public Transportation Association (APTA) conferences. Most of these studies/reports focus on the description, analysis and applicability of various off wire propulsion technologies including On-Board Energy Storage Systems and Ground Level Power Systems. Several reports provide a review and feasibility of proprietary systems such as Primove, Innorail, TramWave and ATS.

SECTION A

Summary Assessment on Streetcar Propulsion Technology

July 2014

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Summary Assessment

on Streetcar Propulsion Technology

For

Council of the District of Columbia

By

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1.0 Advances in Propulsion Technology

Catenary-free or off-wire or wireless propulsion technologies can be grouped into two main categories: On-Board Energy Storage Systems (OESS) and Ground Level Power Supply Systems (GLPSS). These two systems and the individual technologies therein are described below:

1.1. On-Board Energy Storage Systems

Vehicles using this technology are powered by batteries, supercapacitors, flywheels, fuel cells, diesel and/or alternative fuel sources or a combination of these systems.

a. Supercapacitors

Supercapacitors, or double-layer capacitors, store their energy electrically in an electrostatic field. They are used to increase regeneration and lower energy consumption and are also used for off-wire operation. Supercapacitors have been installed on streetcar vehicles in revenue service by almost all major international streetcar builders. For instance, the Spanish firm Construcciones y Auxiliar de Ferrocarriles SA (CAF) initially supplied vehicles with supercapacitors for off-wire operation to Seville in 2010 to accommodate a religious procession where overhead wires would have interfered. Subsequently, CAF supplied off-wire vehicles to Zaragoza, Spain in 2011, and won additional orders for Granada, Spain in 2010 and Kaoshiung, Taiwan in 2012. SIEMENS offers supercapacitors as part of their standard Mobile Energy Storage (MES) designed to fit on the roof of any vehicle.

Figure 1 - Supercapacitor Energy Storage Unit being installed at Tri-Met in Portland, OR

In the United States, a demonstration project funded by a USDOT's TIGER III grant is being conducted by Tri-Met in Portland, Oregon. Supercapacitor banks from American Maglev Technologies are being fitted to 20 SIEMENS LRVs, which will operate in revenue service. The supercapacitor system charging/discharging rate is very fast, measured in seconds, and they can withstand repeated charge/discharge cycling without significant degradation over time.Design life does vary somewhat depending on the degree of cycling, but has been claimed to be on the order of 23 to 30 years.

b. Batteries

Batteries have been installed on streetcar vehicles in revenue service since mid-1800s, which predates the use of an overhead contact wire. Batteries are the most diverse type of on-board energy storage and include lead-acid, nickel-metal hydride, and, lithium-ion (Li) batteries.

Figure 2 - Li Battery by Kinki Sharyo for ameriTRAM LRV prototype

Stadler Rail has demonstrated operation of a Li-battery equipped streetcar in Munich, Germany and the local transit authority has ordered four of the streetcar vehicles.

In the United States, Kinki Sharyo has built a demonstrator prototype, the ameriTRAM, which has toured several cities. Inekon of the Czech Republic is supplying Seatle with six “Buy America” qualified streetcars with off-wire running technology based on Li-batteries and Brookville Equipment Corporation of Pennsylvania is supplying Dallas with two Liberty streetcars with Li-batteries. Since the 1990s, San Francisco MUNI has been using NiCad batteries to power an Emergency Propulsion Unit (EPU) used to move electric trolleybuses off-wire around road obstacles and also to maneuver the trolleybuses in their parking and maintenance facility. The EPU is a high voltage battery pack consisting of 163 cells mounted on the roof of the vehicle. Rail vehicles with longer distance operability using NiMH batteries were placed into service in Nice, France, in 2007.

Figure 3 – ALSTOM Streetcar in Nice, France

The requirement of a chemical reaction results in a longer time to charge and discharge the battery, with charging usually measured in hours. However, batteries can store more energy per unit weight than other on-board storage devices like supercapacitors and flywheels. For long distances, off-wire batteries are far superior to either supercapacitors or flywheels. The slow discharge rate usually results in a lower vehicle acceleration and overall performance.

c. Flywheels

Flywheels store kinetic energy in a high speed rotating drum which forms the rotor of a motor generator. When surplus electrical energy is available it speeds up the drum, storing more kinetic energy. When electrical energy is required, the drum gives up some of its kinetic energy by driving the generator. The Parry People Mover Ltd. (PPM) in England, which has built 12 units for demonstration, uses flywheel technology. ALSTOM also continues to prototype flywheel-equipped Citadis vehicles, but has not yet marketed a model for revenue service operation. The amount of energy that can be stored in a flywheel is comparable to its electrical equivalent, supercapacitors. While future developments may result in attractive technology, flywheels are not ready for streetcars in revenue service applications.

d. Fuel Tanks (Fuel/Electric Hybrids)

Storing energy on board the vehicle to power an engine is common for buses. Compressed Natural Gas (CNG) is a mature technology for buses, but has had minimal success. Three vehicles in Nordhausen, Germany were outfitted with a diesel engine and fuel tank inside the passenger compartment. Adapting this technology to modern low floor streetcars based on electric drive technology is difficult and not cost-effective. Fuel tanks have had no significant streetcar application.

e. Fuel Cells

Fuel cells directly convert fuel to electrical power without the need for an engine or turbine. There are several demonstration projects with electric buses, and 10 prototypes are currently in revenue service at AC Transit in Oakland, CA. The prototypes are using proton exchange membrane (PEM) cells powered by hydrogen or methanol, with hydrogen getting the most interest. The buses use the fuel cells to drive electric motors as well as to charge batteries, which then can assist the electric drives. Almost all work on this technology has been performed on buses with no known applications to streetcars.

1.2. Ground Level Power Supply Systems

These systems distribute power to the vehicle via induction using the ground level power sources.
These proprietary systems include APS by ALSTOM, Ansaldo's TramWave and Bombardier's PRIMOVE.

a. Non-Contact Inductive Power Transfer (PRIMOVE by Bombardier)

Bombardier has developed PRIMOVE - a ground level, off-wire power system which uses non-contact inductive power transfer in combination with the 'Flexity' model tram equipped with an ultra-capacitor energy storage system on the vehicle. The PRIMOVE application uses ground power supply by installing electrical hardware for contactless induction and relies on an electromagnetic field formed between the third rail and a magnet on the vehicle to provide electrical power to the vehicle. When a ground level segment is energized, a 20 kHz, three-phase magnetic field is created. Trains are equipped with pickup coils to receive this energy, which they convert into an electrical current that powers the tram. Transfer of energy is restricted by the distance between the vehicle-mounted collector and in-ground conductor and supplemented by the on-board ultra-capacitor system when needed. Charging of the ultra-capacitor can occur during regenerative braking or during period of light power demand, such as when coasting. The in-ground conductor is switched such that it is only energized when a vehicle occupies the segment underneath the vehicle and is non-powered at all other times. Because the system is contact-less, the vehicle is able to operate in all climates regardless of snow, ice, sand and salt on the rails.The initial testing of the PRIMOVE system began at the Bombardier facility in Bautzen, Germany in 2009 and testing on the streets of Augsburg was completed in 2012. Montreal is expected to begin testing at the end of 2013; the Mannheim test is expected to begin in the second quarter of 2014. Bombardier was recently awarded a contract in China for the construction of the first catenary-free system of its kind in that country, but revenue operations are not expected to begin until 2015-2016.

b. Surface Mounted Contact Rail - APS by ALSTOM

The ALSTOM APS proprietary system uses an in-ground contact power-rail (third rail) installed between the running rails to distribute power, and a shoe power collector installed on the vehicle. Electrical power is transmitted to the vehicle as the shoe collector makes contact with the power-rail. A loop detector installed on the vehicle allows only those segments of power-rail directly below the vehicle to be energized, thereby minimizing the risk for accidental contact between an electrified power-rail segment and pedestrians or any other objects. In the APS system the lengths of the conductor/insulator rail segments are matched to the length of the streetcar. The lengths are set such that two adjacent active segments, followed by an inactive section at each end, are always covered by the streetcar. The APS system has been in revenue operations for over 10 years in Bordeaux, France. APS is also now in use as part of the tram systems in French cities including Tours, Orleans, Angers, Nice, and Reims. The APS has been used in areas with snow, but road salt is not used for de-icing; a biodegradable deicing fluid is used instead. The APS cannot operate when covered with water.

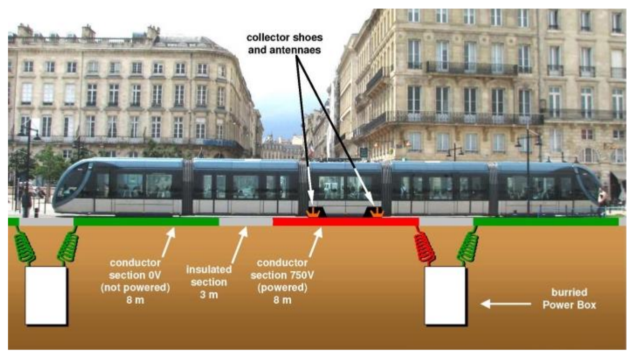

Figure 4 - ALSTOM APS System Components

c. TramWave by Ansaldo STS

Ansaldo STS' TramWave System uses a continuous conduit duct embedded in the ground running between the rails. Power is provided by segmented, insulated conductor strips ranging between 3 and 5 meters in length with each segment activated as the train passes overhead to be powered. A ferromagnetic belt in the conduit lets electricity flow to the streetcar when contact is made with the power collector shoe. Gravity causes the magnetic belt to fall back into place once a train passes by, thereby cutting off the power supply. TramWave can be installed on a variety of vehicles, and can be integrated with traditional catenary lines. All active elements of the system are fully modularized, and can be fitted to various types of track installation, including ballasted track.

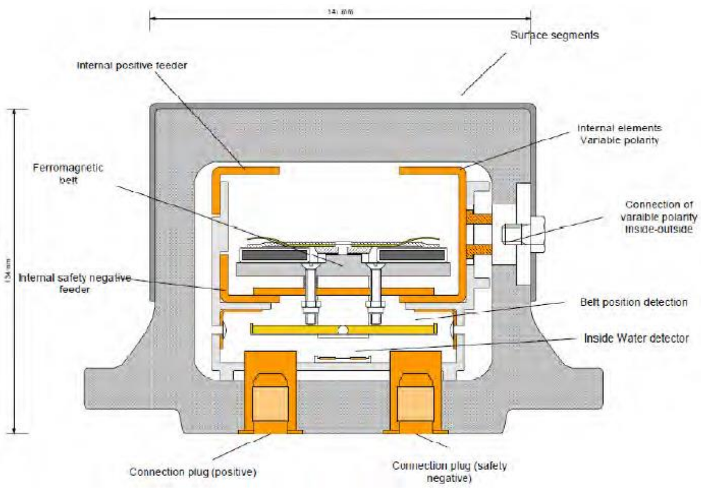

Figure 5 – Ansaldo STS TramWave – Power Rail Cross Section

The track modules also contain a return conductor instead of using the running rails as the return path. This can have substantial benefits by eliminating concerns over the corrosive effects of stray dc currents on underground utilities. The system is covered by several worldwide patents, but Ansaldo STS advertises the TramWave system as being able to fit almost any light rail vehicle or streetcar.

1.3. Analysis and Evaluation

a. Technology Limitations

While the technologies described above have in some applications been successfully operated, the current applications are limited by the state of proven technology and environmental factors. While OESS are operating around the world, the actual demonstrated distances of operations as well as the operating conditions seem to indicate that the technology may be a considerable ways from being able to provide a completely or even substantially off-wire system in the District. Current applications are often operating over limited distances, in moderate climates, on moderate or no grades and in dedicated rights-of-way. The extended distances sought along with the District's environment, which includes occasionally harsh winters and summers, varying grades, operations in high-volume mixed traffic and high passenger demand, likely exceed the state of current OESS technology.

GLPSS options also face constraints and current operations are somewhat limited when compared to the extensive amount of off-wire operations the District eventually hopes to achieve. While topography is less of an issue for these technologies, climate can be a challenge, particularly for exposed (contact surface) GLPSS options, and some systems cannot operate when covered in water. Induction (non-contact) based systems are generally not affected by weather conditions. While the operating technologies contain technology-based safety features and have proven safe to date, some may raise safety questions, particularly in the context of exposed/contact surface GLPSS in mixed traffic. Current applications of modern GLPSS are limited and the technology is its early stages. A final issue with most if not all GLPSS systems is that they involve proprietary infrastructure components, essentially locking the end user into a single supplier, thus eliminating competition in vehicle sourcing well into the future. While specific OESS vehicle technologies may also be proprietary, the proprietary features are generally confined to the OESS components themselves. OESS vehicles in most cases can operate on a wide variety of track infrastructure.

b. Future Development

The interest in off-wire streetcars continues to grow. Most cities would prefer to be able to operate streetcars in a wire-free environment. As such, it is anticipated that this ever-increasing market demand will prompt a good deal of innovation by incentivizing manufacturers' investment in research and development and introducing economies of scale. In keeping with industry in general, at a minimum one would expect that the batteries will become more efficient, smaller in size, and lighter weight. This will permit the streetcars to remain powered and off-wire for a longer period of time, thereby providing the ability to reduce the use of overhead wire over time.

c.Buy America Considerations

This general discussion covers the state of technology currently available in the global marketplace. It should be noted that the DC Streetcar system will be subject to federal Buy America provisions. Although neither has entered revenue operations, there are currently two manufacturers supplying vehicles with some level of off-wire capability that meet Buy America requirements: Brookeville Electric Equipment (BEC) and Inekon (partnered with Pacific Marine). While several of the other manufacturers have expressed interest and the potential capability to deliver off-wire cars that meet Buy America, Inekon and BEC remain the only two companies to have taken orders for such vehicles.

d.Approach

At this time, off-wire streetcar technology remains largely in a developmental stage. While off-wire vehicles have been implemented successfully in limited applications, the various technologies have not proven capable of providing an reliable off-wire system for the entirety of the DC Streetcar system within the District's operating environment. Nonetheless, a certain amount of off-wire operations does seem feasible. Among GLPSS, the non-contact surface rail system transferring power by induction eliminates several issues seen with the contact surface rails and is the most advanced among the ground level power supply systems. With further proven applications of the technology and if the proprietary and Buy America issues can be addressed, non-contact GLPSS may prove a viable alternative at some point the future. Perhaps a more likely alternative in the near term is a hybrid system that combines some level of on-wire (OCS) and off-wire operations. The most likely scenario may be hybrid OCS/OESS vehicles with a combination of batteries and supercapacitors. It is difficult to determine at this stage the precise extent of off-wire operations that could be attainable using this approach. In addition to hybrid OCS/OESS options, hybrid OCS/GLPSS options may also provide promise for implementing these relatively new and proprietary technologies.

While the District seeks innovative solutions to minimize and possibly eventually eliminate OCS in the areas within the original L'Enfant Plan, it must be mindful to only consider solutions that can also provide operational reliability and safety while also providing responsible stewardship over District resources by maintaining reasonable life cycle costs. Balancing these considerations is critical to ensuring that DDOT provides this vitally needed transportation service while also being sensitive to the unique context of our nation's capital. In order to achieve this end, DDOT is proceeding with a consolidated design-build-operate-maintain (DBOM) delivery method for an integrated premium transit system (IPT) which includes the 22-mile Priority Streetcar System (PSS). By utilizing the DBOM approach, DDOT will be seeking a development partner that can best meet the District's varied performance goals for the system. DDOT has issued a request for qualifications (RFQ) for transit teams to deliver the system through a DBOM contract. The outcome of the RFQ will be the selection of short-listed proponents, industry leaders who will ultimately bid on providing a coordinated IPT system. The DBOM contract, while including technical specifications, will focus on performance requirements over more prescriptive specifications in order to allow the industry the level of flexibility needed to bring the highest level of innovation and partnership. Through the RFP development and industry review process, DDOT will gain critical input from the prospective bidders and utilize this input to inform the development of the final performance requirements included in the final RFP. In addition to pushing the industry to maximize the amount of off-wire operations in initial years of revenue service, the RFP will instruct bidders to also outline a plan for expanding off-wire operations as technology and circumstances permit going forward.

2.0 Feasibility, including cost, of converting to non-aerial motive power where aerial wiring has been installed

Two segments of the proposed DC Streetcar System are at or near completion for passenger service.

a. **H Street / Benning Road Streetcar Segment**, ~2.4 miles total length; ~5.0 miles of aerial OCS, 3 high-voltage traction power substations.

b. **Anacostia Initial Line Streetcar Segment**, ~1.0 mile total length, ~ 1.5 miles of aerial OCS, 2 low-voltage traction power substations.

Each segment utilizes aerial-motive power or an overhead contact system (OCS) which includes traction power substations (TPSS) and an overhead contact wire for the delivery of 750dc volts of power to the streetcars through a pantograph. The TPSS supply the 750dc volts of power to the OCS at specific locations through the use of feeder cables mechanically connected to the overhead contact wire. The TPSS are fed primary electrical power by means of low-voltage and high-voltage electricity from Pepco. The use of low or high voltage is dependent upon the proximity of the available power from Pepco, the distances between traction power substations, and the demand of the streetcar segment. The TPSS then convert the primary electrical power to 750dc volts and distribute the power to the OCS through the feeder cables to the overhead contact wire. The negative return current travels through the running rail to the TPSS through a series of rail-to-rail and track-to-track cables at prescribed locations for an efficient electrical circuit.

There are two options to consider when determining the feasibility of converting to a non-aerial power delivery system where aerial-power delivery systems are in place.

i. *Existing aerial power delivery systems remain in place.* In this scenario, the existing poles, OCS and TPSS will remain in place so that there is no associated cost of demolition and/or removal. The cost of conversion from OCS to the new technology can be divided into the following components:

   a. **For OESS (Batteries and/or Supercapacitors Technology)** – The cost of the new vehicles including the batteries, supercapacitors and charging stations will be the added cost.

This is assuming that the streetcar tracks, physical stops and signage items are unchanged between the two technologies. It is also possible that the TPSS can be repurposed to serve as charging stations. It would be required to retrofit the streetcar stations to provide charging capabilities. A high-level estimate of the costs breaks down as follows:

i. Vehicles (including spares) –

   1. Cost Range of a Baseline Streetcar Vehicle:

      a. Low - $5million

      b. High - $7million

   2. Cost factor for adding batteries/supercapacitors:

      a. Low – 10% of baseline cost

      b. High – 30% of baseline cost

ii. Retrofit/install charging stations – In order to reasonably estimate the potential cost to install charging stations or retrofit existing streetcar platforms to accommodate a charging station the proprietary model of vehicle, battery, and/or super capacitor should be identified. The most economical cost approach is when the existing aerial power delivery system (OCS) remains in place and is utilized to recharge batteries or super capacitors. A typical streetcar platform with shelters, pylons, and furnishings is approximately $300,000 each to construct in the District's public space. Any additional facility needed for charging stations would be in addition to the $300,000 baseline cost.

Technical feasibility – As discussed above, on-board energy storage technologies have limitations with the amount of energy that can be stored on the vehicle versus the amount of energy required to operate across a wireless area. Operation in mixed traffic lanes is particularly difficult to estimate as unpredictable but normal events such as an unusually high traffic volume, traffic accident or diplomatic motorcade can extend the time off-wire and exhaust the stored energy before it returns to a charging location or powered track, thereby stranding the vehicle. Topography places additional limits on on-board energy storage systems, as challenging grades exhaust the power supply much more quickly.

b. **For GLPSS (including contact and non-contact systems)** – This system requires the installation of in-ground electrical hardware in combination with the specialized vehicle equipped with power receiver system, an ultra capacitor energy storage system, and vehicle detection and segment control antenna to energize the wayside power cable segment. This is a proprietary system and the costs are not known at this time. However, the installation of this system would require that the existing rail tracks are removed to install the new power cables, vehicle detection and segment control cables, high-voltage inverters, and supervisory control and data acquisition interface for the new in-ground system before the tracks can be reinstalled. The presence of poles, OCS and TPSS may not cause any hindrance; however that remains to be confirmed.

It is important to note that this system is very new and has not been used in revenue service thus far. The current applications are limited to controlled demonstration lines on dedicated right-of-way only. The transference of energy from the wayside to the vehicle depends on maintaining a small gap between the vehicle's collector and the supply rail which may restrict the vertical curve capabilities in areas such as underpasses. Installation and protection of in-street high voltage contactor boxes at frequent intervals is required. The pre-formed rail assemblies are proprietary and available only from a sole supplier.

i. Vehicles (including spares) –

1. Cost Range of a baseline Streetcar Vehicle:
    a. Low - $5million
    b. High - $7million
2. Cost factor for specialized vehicle equipped with power receiver system:
    a. Low – 20% of baseline cost
    b. High – 40% of baseline cost

ii. Existing embedded concrete track & special trackwork demolition:

1. $120 per track foot
2. H/Benning is ~25550 track feet = ~$3.06 million

3. Anacostia is ~7880 track feet = ~$950,000

iii. Replacing embedded concrete track (without proprietary conductor rail):

1. $581 per track foot
2. H/Benning is ~25500 track feet = ~$14.80million
3. Anacostia is ~7880 track feet = ~$4.60million
4. Cost factor for proprietary conductor rail = Undetermined
    a. Labor and equipment to install is assumed or considered to be similar and equivalent to conventional reinforced concrete embedded track installation.
    b. Material cost for proprietary conductor rail is not quantifiable. As the technology is unique to the manufacturer and public information is not available, it is not practical to estimate the costs for these items. In addition to the basic materials that comprise the technology, the research and development costs as well as manufacturing start-up costs for a new technology would need to be recovered by the owner of the technology.

iv. Replacing embedded concrete special trackwork (without proprietary conductor rail):

1. $60,000 per each turnout
2. H/Benning's 11 turnouts = ~$660,000
3. Anacostia's 6 turnouts = ~$360,000
4. Cost factor for proprietary conductor rail = Undetermined
    a. Labor and equipment to install is assumed or considered to be similar and equivalent to conventional reinforced concrete embedded track installation.

b. Material cost for proprietary conductor rail is not quantifiable. As the technology is unique to the manufacturer and public information is not available, it is not practical to estimate the costs for these items. In addition to the basic materials that comprise the technology, the research and development costs as well as manufacturing start-up costs for a new technology would need to be recovered by the owner of the technology.

ii. *Removing aerial power delivery systems including OCS and TPSS.* Street lighting and traffic signal infrastructure has been designed to be accommodated on OCS poles in effort to limit the visual impact poles and wires. If the aerial power delivery system was deconstructed, the existing street lighting and traffic signal infrastructure may have to be reconstructed as well.

a. **For Batteries+Supercapacitors Technology** – The cost of removal of the poles and OCS will be a marginal expense in addition to the costs estimated above.

i. Remove, salvage, & demolish OCS wire, OCS Poles, OCS Hardware, & foundation:

1. $30 per track foot
2. H/Benning is ~25550 track feet = ~$765,000
3. Anacostia is ~7880 track feet = ~$236,000

ii. Remove, salvage, decommission & restore Traction Power Substations:

1. ~$200,000 per tpss unit
2. H/Benning's 3 TPSS units = ~$600,000
3. Anacostia's 2 TPSS units = ~$400,000

iii. Loss of initial investment: The District has invested approximately ~$22 million dollars cumulatively in the OCS, traction power substations, and train control system that makes up the aerial power delivery system on the H/Benning Segment. This includes the mainline and operation/maintenance facility.

b. **For Ground Level Induction System** – The cost of removal of the poles and OCS will be a marginal expense in addition to the costs of the proprietary system discussed above.

   i. Remove, salvage, and demolish OCS wire, OCS Poles, OCS Hardware, and foundation:

      1. $30 per track foot
      2. H/Benning is ~25550 track feet = ~$765,000
      3. Anacostia is ~7880 track feet = ~$236,000

   ii. Remove, salvage, decommission & restore Traction Power Substations:

      1. ~$200,000 per tpss unit
      2. H/Benning's 3 TPSS units = ~$600,000
      3. Anacostia's 2 TPSS units = ~$400,000

   iii. Loss of initial investment: The District has invested approximately ~$7 million dollars cumulatively in the OCS, traction power substations, and train control system that makes up the aerial power delivery system on the Anacostia Initial Segment. This includes the mainline and operation/maintenance facility.

3.0 Feasibility, including cost, of using non-aerial motive power on such segments of the streetcar system where construction has yet to be initiated

a. **For Batteries+Supercapacitors Technology** – The cost of installing the tracks, relocation of utilities, and the construction of streetcar stops can be estimated from the recent H/Benning and Anacostia Initial Line segments. The cost of the new vehicles including the batteries, supercapacitors and charging stations will be the added cost. Additionally, on-board energy storage technologies have limitations with the amount of energy that can be stored on the vehicle versus the amount of energy required to operate across a wireless area. Operation in mixed traffic lanes is particularly difficult to estimate due to unpredictable but normal events, such as an unusually high traffic volume, traffic accident or diplomatic motorcade, which can extend the time off-wire and exhaust the stored energy before it returns to a charging location or powered track, thereby stranding the vehicle.

b. **For Ground Level Induction System** –The cost of installing the tracks, relocation of utilities, and the construction of streetcar stops can be estimated from the recent H/Benning and Anacostia Initial Line segments. The ground-level induction system requires the installation of in-ground electrical hardware in combination with the specialized vehicle equipped with power receiver system, an ultra capacitor energy storage system, and vehicle detection and segment control antenna to energize the wayside power cable segment. This is a proprietary system and the costs are not known at this time. However, the installation of this system would require that the existing rail tracks are removed to install the new power cables, vehicle detection and segment control cables, high-voltage inverters, and supervisory control and data acquisition interface for the new in-ground system before the tracks can be reinstalled.

It is important to note that this system is very new and has not yet been used in revenue service. The current applications are limited to controlled demonstration lines on dedicated right-of-way only. The transference of energy from the wayside to the vehicle depends on maintaining a small gap between the vehicle's collector and the supply rail, which may restrict the vertical curve capabilities in areas such as underpasses. Installation and protection of in-street high voltage contactor boxes at frequent intervals is required. The pre-formed rail assemblies are proprietary and available only from a sole supplier.

4.0 Any recommended amendments to this act, including a potential sunset date

After engaging in a multi-year rigorous public involvement process and collaboration with key stakeholders on streetcar, DDOT continues to seek to implement innovative solutions to minimize and possibly eliminate OCS in the areas within the original L'Enfant Plan. DDOT seeks solutions that will provide both operational reliability and safety while at the same time providing responsible stewardship over District resources. Streetcars have had a long history in the District and operated with the overhead wires in the District for nearly 100 years. The return of streetcars will accommodate growth, enhance mobility, provide Metrorail core capacity relief, and support economic development. DDOT will work with the Council as the streetcar program moves forward to identify any potential amendments to the act.