MURIEL BOWSER
MAYOR

MAR - 8 2017

The Honorable Phil Mendelson
Chairman
Council of the District of Columbia
1350 Pennsylvania Ave., NW, Suite 504
Washington, D.C. 20004

Dear Chairman Mendelson:

Enclosed for consideration and review by the Council of the District of Columbia is the *Assessment of Streetcar Propulsion Technology*, an interim update report as required by the Transportation Infrastructure Amendment Act of 2010. The attached report identifies issues and constraints with different propulsion technologies and provides a cost comparison of technologies used in other cities throughout the United States.

If you have any questions on this matter, please contact Leif Dormsjo, Director, District Department of Transportation, at (202) 671-3238.

Sincerely,

Muriel Bowser
Enclosures

District Department of Transportation

Assessment of Streetcar Propulsion Technolgy

February 2017

WE ARE WASHINGTON DC

District Department of Transportation

Assessment of Streetcar Propulsion Technology

as Required by the Transportation Infrastructure Amendment Act of 2010

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1.0 Introduction

The District of Columbia Transportation Infrastructure Amendment Act of 2010 authorized installation of aerial contact wires to power the DC Streetcar system while designating wire-free zones along the National Mall and Pennsylvania Avenue between the Capitol and White House to protect historically designated viewsheds. The Act also mandated an evaluation of the impact of aerial wires on specified properties and historic districts as part of the formal streetcar Project Development process. This process is being completed for each proposed extension in conjunction with the evaluation and documentation prepared in keeping with the District of Columbia Environmental Policy Act (DCEPA) and National Environmental Policy Act (NEPA).

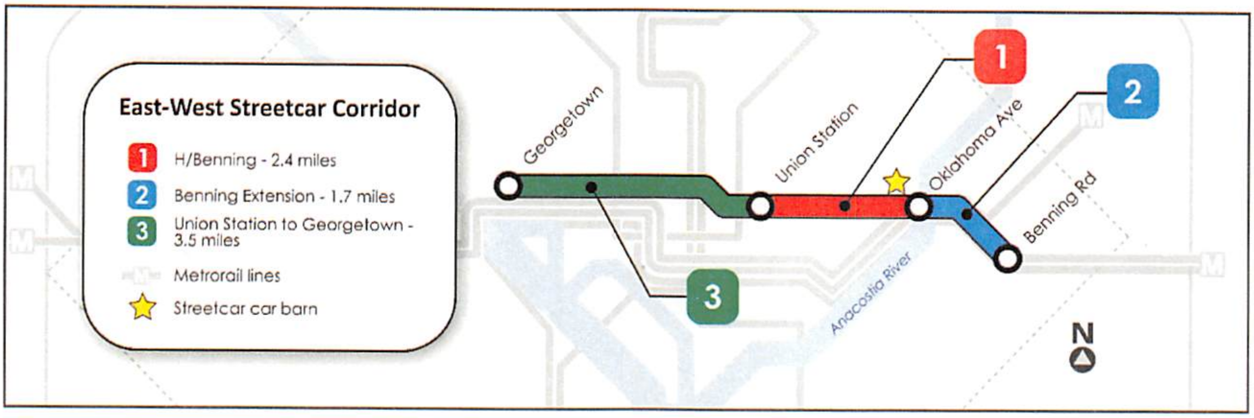
In addition, the Mayor is also required to develop a triennial report on wireless propulsion technology and the feasibility of utilizing non-overhead wire propulsion and charging for both existing streetcar facilities and planned streetcar facilities. The reviews are mandated to be completed by January 1, 2014 and every 3 years thereafter consisting of:

1. Advances in streetcar propulsion technology;
2. Feasibility, including cost, of converting to non-aerial motive power where aerial power wiring has been installed;
3. Feasibility, including cost, of using non-aerial motive power where aerial power on such segments of the streetcar system where construction has not yet been initiated; and
4. Any recommended amendments to this act, including a potential sunset date.

Since submitting the first comprehensive assessment nearly three years ago, DDOT has made significant progress advancing the streetcar program. On February 27, 2016, DDOT opened the H/Benning Streetcar line to passenger service and continues to advance the NEPA processes with partnering federal agencies for final environmental approval to extend the H/Benning line. The eastward extension, terminating at the Benning Road Metro station, is currently in the environmental review process in coordination with the Federal Highway Administration (FHWA). A Draft Environmental Assessment (EA) was released to the public in Spring 2016, and a public hearing was held in May 2016. The EA includes the potential for both on- and off-wire propulsion, and DDOT is currently responding to comments and expanding environmental documentation to respond comprehensively. The Union Station to Georgetown line, extending to the west, continues to advance in coordination with the Federal Transit Administration (FTA) and the Federal Highway Administration (FHWA), along with other District and Federal resource agencies.

A brief description of each streetcar project is provided in the following sections. A map illustrating the East-West Streetcar Corridor is shown in Figure 1.

Figure 1 | East-West Streetcar Corridor



1.1. H/Benning Streetcar

The H/Benning Streetcar began passenger operations on February 27, 2016 with service Monday through Saturday. On September 18, 2016, Sunday service was initiated. H/Benning is a 2.4-mile, double tracked segment serving residents, businesses, commuters and visitors between Union Station on the west and the Anacostia River on the east. Ultimately, the H/Benning line segment will be just one piece of an extended east-west line that will traverse the city from beyond the Anacostia at Benning Metro to the Georgetown waterfront. The eastern turnaround for the line is at Benning Road and Oklahoma Avenue, near the Car Barn Training Center (CBTC). The CBTC will handle storage and maintenance of the vehicles, and will also feature community space for local events. The western turnaround is on top of the Hopscotch Bridge, where passengers can disembark and enter Union Station via the parking garage. Currently there is no fare to ride the streetcar and frequencies are 12 minutes. Hours of operation are as follows:

- Monday-Thursday: 6:00 a.m. – midnight
- Friday: 6:00 a.m. – 2:00 a.m.
- Saturday: 8:00 a.m. – 2:00 a.m.
- Sunday: 8:00 a.m. – 10:00 p.m.
- Holidays: 8:00 a.m. – 10:00 p.m.

1.2. Benning Road Streetcar Extension (East)

The proposed Benning Road Extension is a 1.7 mile eastern extension of the H/Benning line which will extend east across the Anacostia River from Oklahoma Avenue NE to the Benning Road Metrorail Station. This Extension will connect Ward 7 residential neighborhoods in Northeast DC to commercial zones located in the areas near the intersection of Benning Road and Minnesota Ave and across the Anacostia to H Street NE and Union Station. When the Union Station to Georgetown extension is completed, streetcar will provide direct access to the employment core in downtown. The Benning Road Streetcar extension is currently near the conclusion of the environmental process in coordination with the FHWA.

1.3. Union Station to Georgetown (West)

Progress in the planning and development of a Union Station to Georgetown streetcar line has occurred. The 3.5 mile west extension, including nine new streetcar stops is now in the EA phase after having completed an Alternatives Analysis. DDOT expects to complete the environmental process in early 2018. Two build alternatives (Alternatives 2 and 4) are being advanced that incorporate different lengths of dedicated guideway as shown in Figures 2 and 3 (Alternative 1 is the "No Build" alternative and Alternative 3 was eliminated from further consideration due to cost and service parameters). "Dedicated guideway" indicates that streetcars will operate in their own dedicated lane, as opposed to operating in shared lanes with vehicles, such as cars, trucks, and buses, as the H/Benning line currently operates. Each of the alternatives assumes a hybrid propulsion system which includes overhead charging facilities at station stops and strategic locations for vehicle charging (see Figure 4). DDOT continues to coordinate with resource agencies on the locations and specific design elements where vehicle charging will be required. Initial ridership forecasting models predict high ridership for the project as a result of the expected reliable, relatively high-speed service. DDOT is also coordinating with FTA to assess the feasibility of funding a portion of the project through the FTA Capital Investment Grant program.

Figure 2 | Alternative 2: 28% to 51% Dedicated Guideway

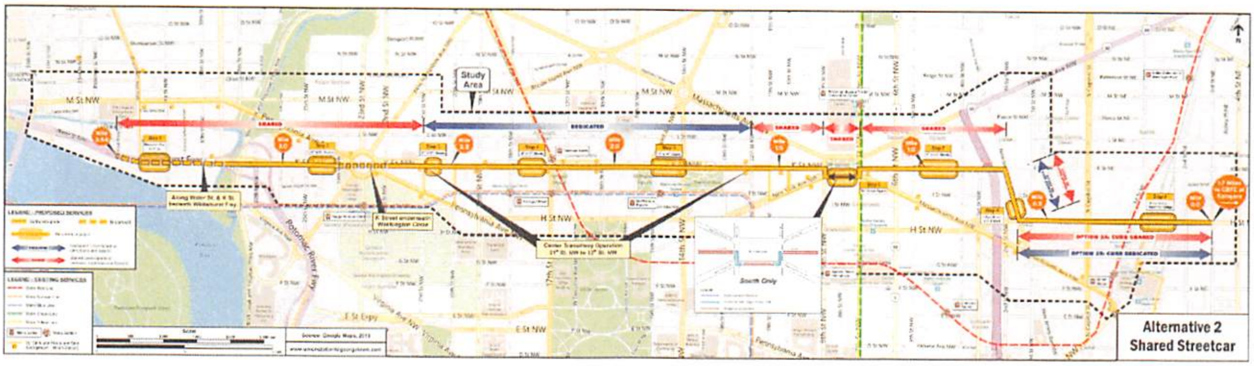


Figure 3 | Alternative 4: 73% to 90% Dedicated Guideway

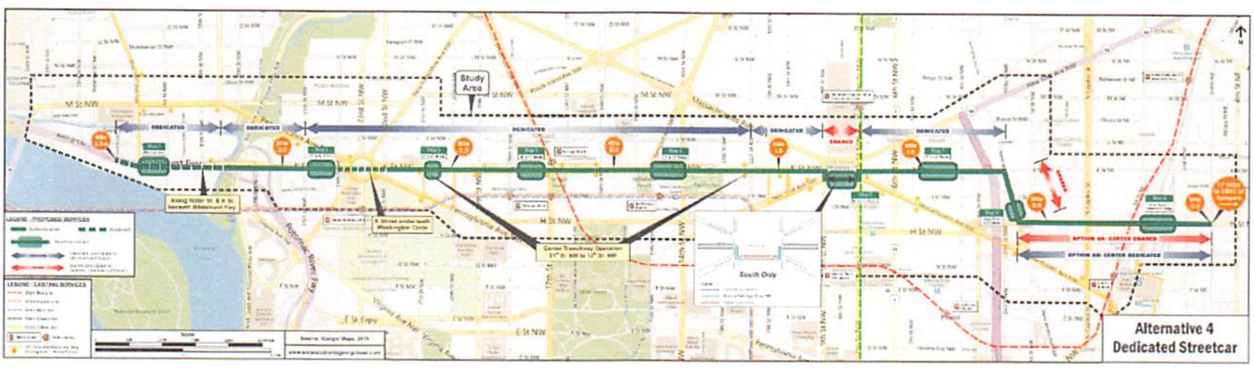


Figure 4 | Union Station to Georgetown: Off-Wire Limits/Charging Station Location

2.0 Advances in Propulsion Technology

The demand for off-wire propulsion technologies has grown as more cities worldwide look to implement streetcar systems. Interest in off-wire technologies is primarily driven by a desire to protect architectural features, sightlines, and viewsheds in often historic urban settings. Additionally, the potential for off-wire technologies to reduce costs by minimizing or eliminating infrastructure requirements associated with traditional overhead contact systems has made for an attractive solution. Over the last decade, substantial advances have occurred in the development of off-wire technologies. The field is evolving so quickly, that any comprehensive assessment can quickly become stale. DDOT's latest evaluation has been developed as part of the Union Station to Georgetown EA process. The technology assessment documents the advancements and feasibility of off-wire propulsion technologies in streetcar applications. A brief summary of the off-wire propulsion technologies and their use in streetcar systems is provided in the following sections.

2.1. Review of Off-Wire Propulsion Technologies

Off-wire propulsion technologies can generally be grouped into two categories: Energy Storage Systems (ESS) and Ground Level Continuous Power Supply Systems (GLCPSS). ESS systems are advancing in the US as battery technology and reliability has rapidly improved and more projects enter revenue service while GLCPSS technology remains largely proprietary. A brief description of ESS and GLCPSS technologies is provided in the following sections.

2.1.1. Energy Storage Systems

ESS, also referred to as On-Board Energy Systems (OBES), are on-vehicle power sources that include such technologies as flywheels, fuel cells, diesel or other alternative fuel sources, batteries, super capacitors, or a combination of these. Among these options, batteries and super capacitors are the most developed and commonly used solutions in the off-wire operation of rail vehicles.

2.1.1.1. Batteries

With numerous variations including Nickel-Metal Hydride (NiMh) and Lithium-Ion (Li-ion), batteries are the fastest developing propulsion technology. Recent and rapid advancement in the development of Li-ion batteries has led to substantial increases in energy storage density and power density and a reduction in charging time to meet minimum requirements for off-wire charging and operation; this advancement has followed the direction and innovation coming out of the automobile industry. Advancements have been made in charging times where a 30-second passenger stop is sufficient to achieve a full charge. The fact that batteries are now considered a proven technology represents a major advance since the previous assessment in 2014. Two streetcar systems in the US are currently utilizing battery technology with several more planned. The Li-ion battery used by Kinki Sharyo for Ameritram is depicted in Figure 5. The NiMH battery used by Alstom in Nice, France is depicted in Figure 6.

Figure 5 | Li-ion Battery Used by Kinki Sharyo

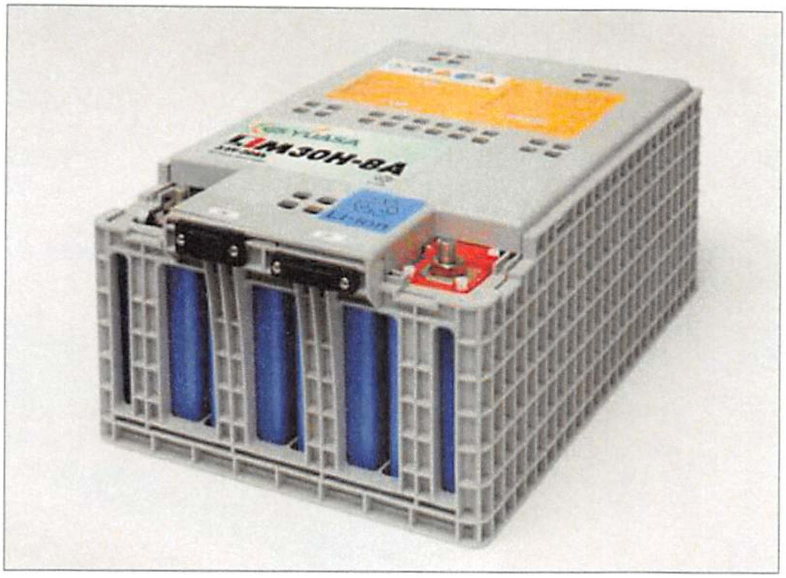


Figure 6 | NiMH Battery in Nice, France

2.1.1.2. Super Capacitors

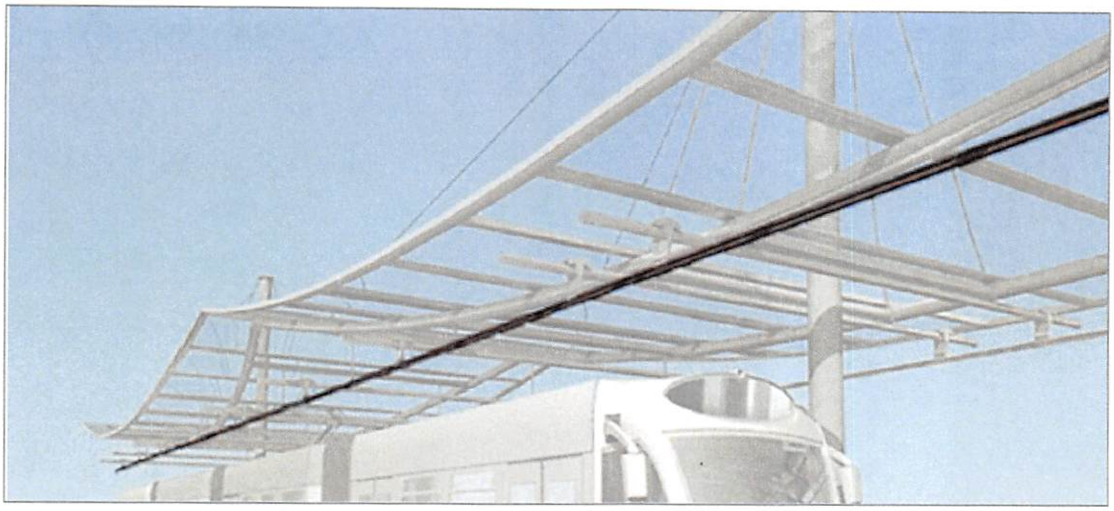
Super capacitors are double-layer capacitors that store energy in an electrostatic field. Features of this technology include a fast rate of charging and discharging and a limited degradation regardless of the volume of the charge/discharge cycles. A majority of rail vehicle manufacturers have incorporated the use of super capacitors in their vehicles. In instances where they have been used for off-wire operation, batteries are often incorporated to provide additional energy and extend the range of super capacitors. Installation of a super capacitor system in Portland, Oregon is depicted in Figure 7.

Figure 7 | Installation of a Super Capacitor System

2.1.1.3. Power Supply Methods

The use of batteries and/or super capacitors for off-wire operation would require charging facilities at select locations. One methodology to deliver electric charge is to incorporate rapid charging technology at passenger stop locations using Rigid Catenary. Rigid Catenary is a stiff, roughly 8" in depth overhead point of contact for a pantograph (an apparatus mounted on the roof of the streetcar to collect power through the catenary wire) that has been used in numerous streetcar systems currently in revenue service. Rigid Catenary is compatible with super capacitors, the combination of super capacitors and NiMH batteries, and Li-ion batteries. Unlike ground level continuous power supply systems (described in Section 2.1.2), Rigid Catenary is not susceptible to inclement weather conditions such as snow and ice. Rigid Catenary technology is currently available through multiple manufactures and is non-proprietary. While there is some visual intrusion with rigid catenary, this can be minimized or mitigated with architectural design. An example of rigid catenary being integrated into passenger stop infrastructure is illustrated in Figure 8.

Figure 8 | Rigid Catenary Integrated within Canopy (Siemens)



2.1.1.4. Issues/Constraints

While ESS allow for off-wire operation, there are some downsides to these technologies. First, ESS components are heavy and may require special streetcar vehicles. They also include an additional cost per vehicle - approximately 10 to 20 percent by most estimates. With a limited supply of power, the use of batteries and super capacitors necessitate a running environment which is relatively flat with consistent operations such that significant delays in operations are rare. Finally, ESS components have a limited lifespan and need to be replaced every 7 to 10 years on average.

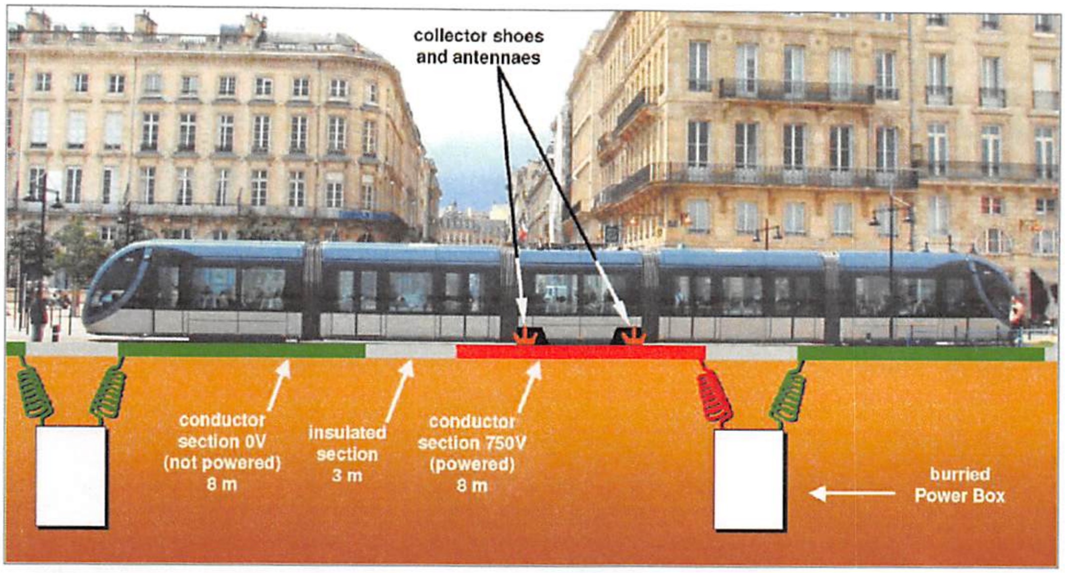
2.1.2. Ground Level Continuous Power Supply Systems

Ground Level Continuous Power Supply Systems (GLCPSS) provide power through one of two ways: direct contact with a separate power rail or non-contact inductive power transfer. GLCPSS is primarily a proprietary technology and has yet to be utilized in the US. The two GLCPSS methods are discussed briefly below.

2.1.2.1. In-Ground Direct Contact with Power Rail

Comparable to the traditional 3rd rail pick-up, this technology incorporates power-pick up shoes that make direct contact with power rails which are only energized when vehicles are directly above, thereby protecting pedestrians, bicyclists, and automobiles that share the right-of-way. Currently there are only two in-ground direct contact with power rail technologies available (Alstom and Ansaldo), both of which are proprietary. The Alstom APS system is currently in use on the Bordeaux tramway in France and the Dubai Tram in the United Arab Emirates. The Alstom APS system is depicted in Figure 9.

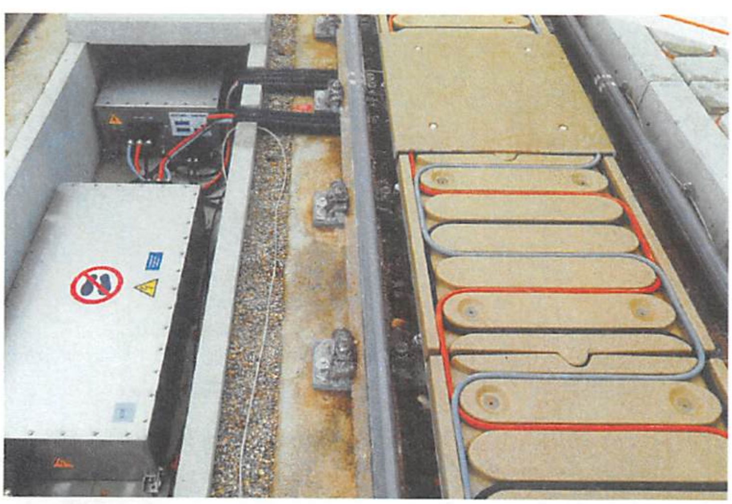
Figure 9 | Alstom APS System (source, Systra 2012)



2.1.2.2. In-Ground Non-Contact Inductive Power Transfer System

With in-ground non-contact inductive power transfer systems, underground components are installed between the rails along a portion of the alignment and only powered when vehicles are directly above. Connection to a power network is made to electrical current inverters installed along the tracks themselves and the vehicles convert the energy to electrical current. Bombardier is currently the only manufacturer offering an inductive technology system and it is proprietary. Bombardier's proprietary inductive power transfer system, PRIMOVE, is illustrated in Figure 10.

Figure 10 | Bombardier PRIMOVE System



2.1.2.3. Issues/Constraints

There are several issues related to ground level continuous power supply systems. First, the existing systems (vehicles and infrastructure) are proprietary in nature and still primarily in the experimental stage (with the exception of APS). They also tend to have higher capital and operating costs. Furthermore, as evidenced by Washington DC's original streetcar line, these systems are vulnerable to damage from snow and ice.

2.2. Implementation of Off-Wire Systems

The development and refinement of off-wire propulsion systems has evolved into a multitude of vendors and offerings since 2014 when no off-wire systems were in operation in the US. At the 13th National Light Rail and Streetcar Conference (November, 2015), it was reported that 17 different cities worldwide have deployed or are actively implementing systems that would feature off-wire operations for at least some portion of their alignment. A total of 11 suppliers were providing vehicles for these off-wire projects. This growth in manufacturing capability improves the prospects for procuring off-wire vehicles in the future at competitive prices.

Since 2014, two US cities have delivered an operating off-wire streetcar project. Dallas and Seattle are currently operating streetcars with off-wire technology in strategic operating environments, supplemented by on-wire segments. In addition, Detroit, Charlotte, Oklahoma City, Milwaukee, and Tempe are implementing streetcar systems with off-wire segments. Each off-wire segment is unique given operating environments and propulsion requirements. All US cities implementing off-wire streetcar systems use or are planning to use on-board energy storage through the use of batteries to achieve operations. No US cities to date have utilized super-capacitors or ground level continuous power supply systems to power streetcar vehicles.

3.0 Feasibility, Including Cost, of Converting to Non-Aerial Motive Power where Aerial Wiring has been Installed

Application of an off-wire technology for the existing H/Benning segment may be technically feasible but at present is not suggested. In order to be feasible, an off-wire technology must be relatively cost effective in the running environment in which it is employed while yielding consistently acceptable operations.

The conversion of H/Benning to off-wire operations is likely to consist of three basic cost elements: vehicle fleet refitting, removal of overhead infrastructure, and charging infrastructure. Order of magnitude costs for these elements have been identified are summarized below.

- Vehicle fleet refitting but more likely replacement - ~ $5.0-5.5M per vehicle
- Removal of overhead infrastructure - ~ $1.0M per mile
- Charging infrastructure - ~$3.0-5.0M per mile

This is likely to yield a cost to convert H/Benning to off-wire operations in the range of $40-50M. While this would be an expensive effort, it could likely be done in conjunction with other construction and vehicle mid-life overhaul efforts to minimize costs. However, general traffic and emergency operations, in particular on the H Street segment, are likely too variable to yield an operating environment that is conducive to off-wire streetcar operations at present. Off-wire streetcar operations need a consistently higher speed, interruption free environment to function. Yet the streetcar operation are subject to traffic delay and emergency operations that can at various points lead to significant delay which could lead to significant battery discharge. It is the assessment of DDOT that the existing off-wire technology does not yet overcome the inconsistent operations of H Street NE to warrant the transition of the existing streetcar service to off-wire operations. However, DDOT will continue to evaluate advances in propulsion and consider opportunities to retrofit the existing facility as we advance extension on both ends.

4.0 Feasibility, Including Cost, of Non-Aerial Power beyond H/Benning

Use of off-wire technology for the balance of the Streetcar system beyond the currently operating segment of H/Benning appears to be technically feasible with the exception of locations with relatively steep grades and inconsistent traffic operations. Off-wire streetcars require no more space or special right-of-way than do streetcars that use a pantograph to contact the overhead wire for power. Depending on the technology selected, the power distribution system could be no more complex or costly than the currently deployed technology on H/Benning.

In addition, the industry has made significant advances in both technology as well as implementation of off-wire systems. Since 2014 both Dallas and Seattle have implemented streetcar systems with off-wire operations at little or no additional cost and multiple other cities are in the process of implementing off-wire systems. Further, car-builders are actively marketing off-wire vehicles that meet Federal "Buy America" provisions.

4.1. System Approach

DDOT is advancing a hybrid off-wire approach since propulsion technology is mature to the point that reliable operation of streetcars can be expected if streetcar running ways provide for reliable operations. To provide a higher level of certainty for successful operations and to create a transit service which is faster and more reliable, DDOT is working to maximize the amount of dedicated guideway available for streetcar. Dedicated transit facilities provide better schedule reliability and thus vehicle performance for off-wire systems while also improving service for passengers. Initial electrical charge modeling of this approach suggests that streetcars utilizing existing hybrid off-wire technology can operate successfully in this environment. As such, DDOT has concluded that hybrid streetcar technology is feasible and a reasonable solution for constructing and operating a streetcar system in the District of Columbia. Overhead wires may be necessary in some locations where they will not impact historic resources to ensure reliable service but for large areas of the system, it is most likely that DDOT will operate without wires employing an onboard energy storage in the form of batteries and super capacitors. Specific corridor-level decisions will be made through each corridor specific planning process.

4.2. Assessment of Cost

Each streetcar project is unique given operating environment and conditions. For example, dedicated guideway for streetcar operations yield a completely different set of propulsion requirements than for operations in mixed-flow vehicle traffic. Additionally, utilization of hybrid off-wire technology does not determine whether a streetcar line will be more or less expensive than its on-wire equivalent. Variables such as utility relocation, right-of-way, signaling, communication, and stations are much better predictors of costs than utilizing on or off-wire technology. As such, drawing comparisons between projects is difficult and potentially misleading.

DDOT has made an assessment of costs comparing a typical one-mile segment of streetcar to understand the cost difference between on-wire and off-wire systems. Generally, the cost of on-wire systems is approximately 2-3% higher than off-wire systems. Costs for the on-wire system are higher for infrastructure related to the overhead catenary system such as poles, foundations, hardware, and wire, typically between $2.0 and $2.5 million more per mile. However, based on the experience of other cities, hybrid vehicles cost up to $500,000 more per vehicle to include the on-board energy storage system, which would balance much of the savings from reduced infrastructure costs. Regardless of the environmental benefit of off-wire technology, off-wire technology appears to be marginally more cost effective than on-wire technology, though the marginal potential cost benefit of hybrid systems must be weighed against their operational constraints.

Other cities have also found that off-wire operations can be cost effective. The Dallas Area Rapid Transit (DART) South Oak Cliff line uses off-wire technology for about one mile of its length while operating in dedicated guideway over the Trinity River Bridge; total length is 1.6 miles.[1] The total cost of that line was $60 million or $37.5 million per mile. Valley Metro is advancing a 3.4-mile streetcar project in downtown Tempe. The project includes two off-wire segments, each approximately 0.75 miles. Total capital costs for the Tempe project, inclusive of 6 off-wire streetcar vehicles, is $186 million (2016), or about $55 million per mile. Seattle First Hill Streetcar System operates both on-wire and off-wire. First Hill is a 2.5-mile, $134 million project with a per mile cost of $53.6 million. In general streetcar costs (off-wire and on-wire) vary based on year of delivery, number of vehicles, track mileage, whether or not a maintenance facility is included in the capital cost, and the level of utility relocations required. In

[1] https://www.dart.org/about/expansion/dallasstreetcar/fonsi/UnionStationtoOakCliffFONSI.pdf

general streetcar costs are averaging $60-$65 M per mile. Information related to other cities pursuing off-wire streetcar operations is show in Table 1.

Table 1 | US Cities Pursuing Off-Wire Streetcar Operations

Location	Length (Route Miles)	Technology	Car Builder	Launch	Project Cost	Per Mile Cost
Dallas, TX (Phase I)	1.6 miles	Hybrid – Battery/Catenary	Brookville	2015	$60.0M	$37.5M
Seattle, WA (First Hill)	2.5 miles	Hybrid – Battery/Catenary	Inekon	2016	$134.0M	$53.6M
Detroit, MI	3.3 miles	Hybrid – Battery/Catenary	Brookville	2017	$141.9M	$43.0M
Milwaukee, WI	2.5 miles	Hybrid – Battery/Catenary	Brookville	2018/2019	$128.1M	$51.2M
Tempe, AZ	3.4miles	Hybrid – Battery/Catenary	Brookville	2019	$186.0M	$54.7 M
Oklahoma City, OK*	4.6 miles	Hybrid – Battery/Catenary	Brookville	2019	$131.0M	$57.0M
Ft. Lauderdale, FL	2.8 miles	Hybrid – Battery/Catenary	TBD	2020	$195.3M	$69.8 M
Charlotte, NC	2.5 miles	Hybrid- Battery/Catenary	Siemens	2020	$150.0M	$60.0 M

Source: HDR Engineering, December 2016

** Oklahoma City Streetcar is 4.6 route miles of single direction track rather than double track. For comparison purposes, the cost per mile assumed double track at 2.3 miles.*

4.3. Union Station to Georgetown

The Union Station to Georgetown (USGT) streetcar extension is advancing assuming a hybrid propulsion system which utilizes hybrid off-wire technology with charging facilities at stations and overhead contact for steep and below grade segments. The USGT project team has advanced this approach in coordination with FTA, FHWA, the State Historic Preservation Office (SHPO), the National Capital Planning Commission (NCPC) and other District and Federal resource agencies, along with other stakeholders in the corridor (including ANCs, community institutions, and the general public). This approach protects corridor viewsheds by minimizing the visual intrusion of charging stations and locating overhead wires well outside of sensitive viewsheds. Charging facilities, potentially at all of the nine new stations, would be designed to be out of view from the crossing streets and locations for overhead contact will be limited to at most the Hopscotch Bridge, under Washington Circle, and under the Whitehurst Freeway.

In addition, DDOT has developed conceptual station and charging design concepts. Figure 11 shows an example of a median station design integrated with station charging infrastructure. DDOT has also been assuming that the vehicle operating in this section would have a pantograph that would be raised or lowered by the operator at specific locations. Figure 12 shows the hybrid streetcar vehicle utilized by DART in Dallas.

Figure 11 | Conceptual Median Stop with Station Charging

View From Stop

Figure 12 | Dallas/DART Hybrid Streetcar Vehicle with Pantograph Down

4.4. Benning Extension

Propulsion for the Benning Extension may be provided by either on-wire or off-wire systems. The ongoing environmental process is considering both options and will conclude with a suggested approach. The operating environment for the Benning Extension contains segments which may yield inconsistent operations, in particular for the bridge over the CSX rail tracks and DC 295 (Anacostia Freeway) and the portion of Benning Road between Minnesota Avenue and East Capitol Street. DDOT is in the process of performing more detailed analysis in order to make a propulsion recommendation for this extension. The propulsion approach for the Benning Extension also needs to be considered in the context of the approach to the system as a whole. An off-wire approach for the Benning Extension needs to be consistent with the approach to retrofit the H/Benning line and the approach to the Union Station to Georgetown extension to create an interoperable system.

5.0 Recommended Amendments to the Transportation Infrastructure Amendment Act of 2010

DDOT does not have any recommended amendments to the Act at this time.