ZERO-EMISSION BUS FACILITY ANALYSIS

FINAL REPORT

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VERSION 3.0

PREPARED FOR

SEPTA

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EXECUTIVE SUMMARY

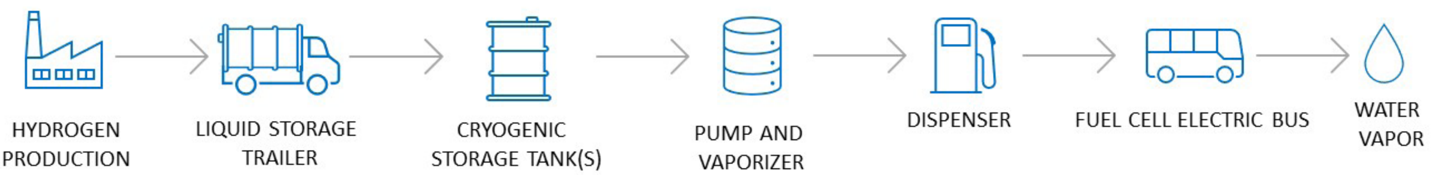
This report summarizes the WSP Team's analysis of requirements, conceptual facility layouts, and estimated costs to install hydrogen storage and fueling facilities at six of SEPTA's eight bus depots, to support a total fleet conversion to fuel cell electric buses (FCEBs) at these locations. ***The report details that there is sufficient space at these six depots for SEPTA to go 100% FCEB.***

The report shows that liquid hydrogen storage and fueling is feasible at six of the eight depots. It identifies additional investments required at two of these depots (Midvale and Victory) to provide satellite fueling of FCEBs assigned to the remaining two depots (Allegheny and Callowhill) without significantly impacting bus parking capacity or operations.

The report shows the estimated capital cost of hydrogen fueling infrastructure to be significantly lower than the capital cost of battery electric bus (BEB) charging infrastructure at all SEPTA depots, and the electrical load and resulting utility upgrades are significantly lower for hydrogen fueling than for BEB charging.

Figure 1 illustrates the liquid delivered lifecycle of hydrogen fuel.

Figure 1. *Flow of liquid hydrogen fuel, from production to emission*



The hydrogen fueling scenario assumed for each site involves purchase by SEPTA of liquid hydrogen, to be delivered to each site by tanker truck. At each depot the liquid hydrogen would be transferred from the tanker truck to an on-site liquid storage tank(s) with capacity for 1 – 2 days of bus fueling. Between four and ten tanker truck deliveries of liquid hydrogen would be required per week (depending on the depot), mirroring existing diesel fuel deliveries. During nightly bus fueling operations, liquid hydrogen would be pumped from the storage tank(s), evaporated, brought up to pressure and delivered to on-bus hydrogen tanks as a high-pressure gas via one or more hydrogen dispensers.
Significant advantages of implementing hydrogen fueling for the SEPTA bus fleet over alternative zero-emission technologies includes major capital cost savings and significantly reduced need for utility upgrades. Estimated startup costs for implementing hydrogen fueling are nearly $180 MM less than the estimated startup costs for installing battery electric bus charging infrastructure. Additionally, battery electric charging is projected to have 38 MW greater connected electric load than the total connected load of hydrogen fueling equipment to support fuel cell buses across the eight depots analyzed.
The analysis determined that SEPTA's largest depot (Midvale) would require 45,000 gallons of liquid hydrogen storage (3 tanks) if fueling only its own assigned buses, or 60,000 gallons of storage (4 tanks) if also providing satellite fueling for buses assigned to Allegheny. Similarly, Victory would require 30,000 gallons (2 tanks) to fuel its own buses, or 45,000 gallons (3 tanks) if also fueling buses from Callowhill. Two of the remaining depots would require 30,000 gallons (2 tanks) and two would require 15,000 gallons (1 tanks) each. There is sufficient space at all the depots to install the necessary hydrogen storage tanks, pumps, vaporizers, and compressors without significantly impacting bus parking capacity or depot operations, with two exceptions - Allegheny and Callowhill – which each occupy an entire city block.
At all depots the hydrogen dispensers would be installed in existing indoor fueling lanes where diesel fueling currently takes place. This will require installation of 2-hour fire rated walls to separate the fueling lanes from the rest of the building; and changes to ceiling mounted heaters, lights, and conduit to remove ignition sources; enhanced ventilation; and installation of hydrogen detectors in the fueling lanes.

The estimated cost of installing the hydrogen storage and fueling infrastructure ranges from $6.5 MM at Frontier to $16.1 MM at Midvale (including satellite fueling for Allegheny at Midvale raises this to $20.6 MM). This includes exterior upgrades and hydrogen equipment, interior upgrades to fueling lanes, exterior electrical upgrades, and hydrogen safety systems. It does not include retrofits to depots buildings or bays beyond the fueling area, interior electrical upgrades, or modifications to indoor bus parking or maintenance areas to accommodate hydrogen fueling.

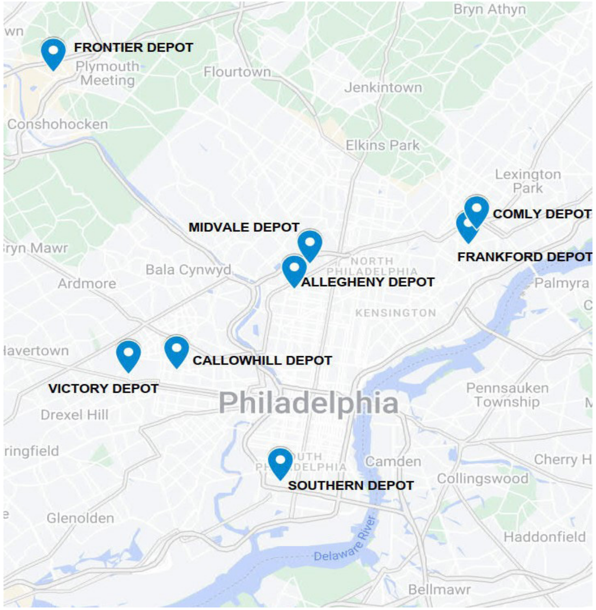
The estimated peak electrical load for operating the hydrogen fueling equipment ranges from 510 kW at Frontier to 1850 kW at Midvale (2200 kW with Allegheny satellite fueling); assuming that each hydrogen fuel station requires 350kW to operate. This compares to an estimated peak load for BEB charging of 5940 kW at Frontier and 6120 kW at Midvale.

Figure 2. Hydrogen fueling yard at AC Transit, an Oakland, CA based public transit agency

BACKGROUND AND CONTEXT

SEPTA Bus Fleet and Facilities

Figure 3. SEPTA Bus Depot locations considered



SEPTA operates a fleet of 1,370 40-ft and 60-ft transit buses, providing fixed route service on 156 routes across the Philadelphia metropolitan area. Current buses are powered by diesel engines or hybrid diesel-electric drive systems. **Table 1** shows the composition of the current fleet by bus and drive type.

SEPTA transit buses operate from eight bus depots located across the metro area (see **Figure 3**). The number of buses assigned to these depots ranges from 105 at Frontier to 307 at Midvale. Some depots are located in dense urban neighborhoods while others are in more suburban or semi-industrial areas. Some depots have bus parking and maintenance areas within the same building, while others have one or more buildings dedicated to maintenance and fueling activities and uncovered outdoor bus parking. **Table 1** shows details of the parking and neighborhood context for each depot.

Table 1. Depot facility details

Depot	Fleet Size 40' Buses	Fleet Size 60' Buses	% of Fleet	Facility Size (SF)	Parking Type	Neighborhood	Special Notes
Midvale	245	62	22%	443,000	Canopy structure with open sides. Roof is open web joists.	Urban area. Facility is bordered by a rail yard, scrap metal facility, and roadways.	Adjacent to SEPTA rail facilities and CSX rail facilities.
Allegheny	47	81	8%	N/A	Enclosed overhead structure with open web joists; buses parked on linear tracks.	Urban neighborhood. Facility occupies one city block.	Urban location with no outdoor space. 1.5 miles from Midvale Depot.
Comly	148	21	13%	105,000	Enclosed overhead structure with open web joists; buses parked on linear tracks.	Urban neighborhood. Facility occupies one city block	Urban location with limited outdoor space.
Frankford	132	0	10%	102,000	Enclosed structure, steel girders.	Urban neighborhood. Facility occupies one city block adjacent to the Frankford Transportation Center.	Depot also houses rubber-tired trolleys. Part of site is equipped with overhead catenary power system.
Victory	145	0	12%	32,000	Outdoor Parking.	Urban area. Facility is bordered by rail lines, roadway, and Cobbs Creek.	High Priority for FCEB due to assigned suburban routes with high daily energy demand.
Callowhill	177	0	12%	N/A	Enclosed Structure with concrete beams.	Urban neighborhood. Facility occupies one city block.	Urban location with no outdoor space. 1.9 miles from Victory Depot. Depot services steel wheel PCC trolley cars and diesel & diesel hybrid buses.
Southern	186	21	16%	217,000	Enclosed structure: some bays have open web joists; others have concrete beams.	Urban neighborhood. Facility occupies one city block	This facility is equipped with 25 55-kW Proterra chargers.
Frontier	105	0	7%	45,000	Outdoor Parking.	Suburban location; adjacent to car dealership on two sides.	High Priority for FCEB due to assigned suburban routes with high daily energy demand.

The **Midvale** bus depot is SEPTA's largest, housing 245 40-ft transit buses and 62 60-ft articulated buses. It is bound by a SEPTA-owned ring road on three sides and a private scrap metal business on the west side. The facility includes a building with fueling and maintenance bays and an overhead canopy structure which provides the majority of bus parking. The SEPTA-owned property includes an 8-mW Combined Heat and Power (CHP) facility, a small grass area along the east side of the property, and a gravel storage lot north of the CHP building. Of the eight depots analyzed, the Midvale facility has the most available land, making this depot an attractive location to build hydrogen storage and fueling infrastructure for FCEBs.

Just 1.5 miles to the southwest, the **Allegheny** bus depot occupies a full city block with a single building covering virtually the entire site from sidewalk to sidewalk. Allegheny houses 47 40-ft transit buses and 81 60-ft articulated buses. There are row homes across the street to the north, east, and west facing sides of the building, and a school and parking lot to the south. Given that the only paved outdoor space is a small apron at the bus entrance and exits onto

West Allegheny Avenue, all depot activities and bus circulation occurs within the building envelope. Due to these space constraints, it is not feasible to implement hydrogen storage and fueling at Allegheny, so Allegheny FCEBs would need to be fueled at another facility, likely Midvale.

Two of the bus depots analyzed, Frankford and Comly, are located a half-mile apart in Northeast Philadelphia. The **Comly** bus depot site is bound to the north, east, and west by blocks of row houses along Saul, Benner, and Comly Streets, and to the southeast by a cemetery across Bustleton Avenue. This depot houses 148 40-ft transit buses and 21 60-ft articulated buses. About three quarters of the site is occupied by a single building that houses the fuel and wash lane, maintenance bays, and indoor bus parking. There is also a paved area of outdoor bus parking to the northeast of the building along Benner Street. To the southeast of the building is paved employee parking along Bustleton Avenue.

Half a mile to the south along Bustleton Avenue, the **Frankford** bus depot, with 132 40-ft transit buses assigned, consists of a single building that houses maintenance bays, fueling lanes, and indoor bus parking. To the northeast of the building on the site there is outdoor parking for rubber-tired trolleys, with overhead catenary power over the parking tracks. Several bays on the northeast end of the building are also dedicated to trolley maintenance, and there is a catenary-equipped pass-through lane for trolleys at the southwest end of the building as well. The rest of the building houses and services diesel and diesel hybrid buses. The site is bounded by roads on three sides and the Frankford Transportation Center to the southeast, which the bus depot is a part of. There is a large playground across the street to the northwest, employee parking and houses to the southwest, and a train depot to the northeast. There is limited pavement around the northwest and southwest sides of the building that is mostly used for site circulation, with limited space for bus parking or queuing, and a wide concrete apron between the building and the Frankford Transportation Center which is used for bus circulation. There is a large SEPTA-owned employee parking lot across the street to the southwest. Light rail lines run from here to the 69th Street Transportation Center, and rubber-tired trolleys also operate out of this facility.

The **Victory** bus depot is located adjacent to the 69th Street Transportation Center, which is a SEPTA terminal in Upper Darby, just west of the city limits of Philadelphia. Housing 145 40-ft transit buses, this facility consists of a maintenance building, a separate fuel and wash building, and outdoor bus parking on horizontal tracks. The site is bounded by Cobbs Creek to the north, SEPTA light rail tracks to the south and west, and Victory Avenue to the east. The site also includes a paint shop and is connected to a gravel storage area adjacent to the light rail tracks to the west. The Victory facility is a high priority for FCEBs due to the high daily energy demand of the suburban routes operating out of this facility.

The Callowhill and Frontier bus depots primarily service suburban routes. The **Callowhill** bus depot, with 177 40-ft transit buses, occupies a full city block, with a single building covering virtually the entire site from sidewalk to sidewalk. The site is bounded by city streets on all four sides, with row homes across the street on three sides, and a park on the fourth. The only paved outdoor space are small aprons at bus entrance/exits onto N 58th Street and N 59th Street. There is no interior bus circulation within the building. Circulation from parking tracks for fueling/servicing occurs on surrounding streets. The northern one third of the building is dedicated to steel wheel PCC trolley cars, and these bays are equipped with tracks and overhead catenary system. The remainder of the building houses and services diesel and diesel hybrid buses. Due to these spatial constraints, it is not feasible to implement hydrogen storage and fueling operations at Callowhill, so Callowhill FCEBs would need to be fueled at another facility, likely Victory.

The **Southern** bus depot houses 186 40-ft transit buses and 21 60-ft articulated buses. The facility consists of a single large building that houses maintenance bays, fueling lanes, and indoor bus parking. On the site there are paved areas to the south and east for both outdoor bus parking and site circulation. The site is bounded by streets to the north, east, and west and a private business to the south. There is a public park across the street to the east and the rest of the surrounding neighborhood is a mix of housing and commercial.

The **Frontier** bus depot, which has 105 40-ft transit buses assigned, is located in Conshohocken, 13 miles northwest of Center City Philadelphia. The high daily energy demand of the suburban routes serviced makes this depot a high priority for FCEBs. The site is bounded on one side by Alan Wood Road and bound on the west and south sides by auto dealer parking lots. There is a stream to the north of the site. The depot includes a fuel/wash building, a maintenance building, and significant paved areas for exterior bus parking. Buses are primarily parked in angled spaces rather than on linear tracks.

Further information about the layout and operations at each depot is included in **Appendix A – Existing Facility Conditions.**

SEPTA ZEB Playbook

SEPTA is committed to transitioning away from diesel powered buses to ensure a clean, sustainable, and resilient future. The agency is planning for a full transition to all zero-emission buses (ZEBs), which could include a combination of BEBs and FCEBs. SEPTA has developed a Zero-Emission Bus Playbook that outlines the planning and analysis to support a full transition by the year 2040.

Figure 4. *Bus parking bay at Frankford Depot*

SEPTA's plan for a transition to all ZEBs is presented as a "playbook" in order to convey that it will be a planning process, and implementation decisions will continue to be refined over time. The 15- to 20-year transition period will include significant facility upgrades that need to be planned years in advance, while also monitoring constant improvements in zero-emission bus technology. Navigating this dynamic will require a flexible approach within the context of a longer-term vision that can continue to be refined over time. The analysis presented in the playbook provides direction for how SEPTA can transition to all zero-emission buses by the year 2040, including where to prioritize initial investments and next steps for piloting concepts and beginning the implementation process. Future iterations of the playbook will incorporate lessons learned from piloting implementation concepts, additional analysis on key topics and additional technology monitoring over time.

The ZEB Playbook currently anticipates that SEPTA may employ both BEBs and hydrogen FCEBs in the fleet transition, and that the decision of which technology to employ has not been finalized, even for depots identified as targets for early conversion.

The playbook identifies the following significant potential benefits of FCEBs relative to BEBs:

- Longer range, and fewer buses required for current service levels, particularly at Victory and Frontier Depots
- Significantly shorter fueling time
- Significantly lower electric power demand, with minimal utility upgrades required
- Enhanced operational resiliency in the event of grid power outage

While FCEBs have advantages relative to BEBs, there are also potential limitations to their use:

- Hydrogen storage and fueling is not feasible at two depots (Allegheny and Callowhill) due to lack of outdoor space.
- Of the other six depots hydrogen fueling was initially judged to be feasible without significantly impacting depot capacity only at Midvale and Frontier. The other depots require additional study to identify the full impacts and cost of hydrogen storage and fueling
- Commercial hydrogen supplies are limited and delivered fuel is more expensive than electricity

This report is intended to inform future versions of the ZEB Playbook by further investigating the cost and facility impacts of hydrogen fueling facilities at all SEPTA depots. The analysis included evaluation of equipment required at Midvale to fuel FCEBs assigned to Allegheny, and equipment at Victory to fuel FCEBs at Callowhill.

Process to Develop this Report

The conclusions summarized in this report were developed based on the following tasks and analyses:

- Preliminary site visits to all eight of SEPTA's bus depots conducted over a two-day period in July 2022, to assess existing conditions, current depot operational practices, and constraints related to installation of hydrogen fueling
- Analysis of codes and standards related to facility design for safe use of hydrogen as a vehicle fuel
- An estimate of daily hydrogen use (kg) for 100% FCEB operation at each depot, based on current bus assignments and daily in-service mileage and diesel fuel use provided by SEPTA
- Literature review and manufacturer outreach to identify configuration, space claim, capacity and throughput, electrical requirements, and cost of commercially available hydrogen storage and fueling equipment
- Conceptual fueling station designs for each depot to comply with applicable codes and standards and provide daily fueling to a 100% FCEB fleet without significantly interfering with or impeding existing depot operational practices
- Conceptual-level cost estimates for purchase and installation of hydrogen storage and fueling equipment included in conceptual designs for each depot

This report does not address requirements for modifications to maintenance bays or indoor parking areas for the safe use of hydrogen; this was beyond the project scope.

This plan was developed by WSP, 1700 Market Street, 10th floor, Suite 1050, Philadelphia PA 19103, under the supervision of Dana Lowell. Mr. Lowell serves as WSP's National Zero-Emission Senior Technical Advisor, with 36 years of experience, including 25 years directly in the transportation industry and government sector. Mr. Lowell has recently supported the Maryland Transit Administration to implement their Zero-Emission Transition Plan, managed a feasibility study to assess the operational requirements and costs for electrification of the Milwaukee County Transit System, among numerous other projects. He is part of a team developing technical and contractual requirements, and procurement documents, to outsource design, installation, operation, and maintenance of electric bus charging infrastructure at two bus depots.

DESIGN CONSIDERATIONS FOR HYDROGEN FUELING

In order to accommodate hydrogen fuel cell vehicles, a set of building codes and standards have been developed to ensure safe fueling. Hydrogen fuel cell vehicles use on-board compressed gaseous hydrogen to operate a fuel cell in the same manner that gaseous fuels are stored on more conventional vehicles. Hydrogen is approximately fourteen times lighter than air, so although the gas is highly flammable, any escaped hydrogen dissipates very quickly.

Similar to requirements for use of other gaseous transportation fuels such as natural gas, there are seven key items to be addressed in retrofitting a facility for use of hydrogen fueled vehicles. These are as follows[1]:

1. Increased ventilation airflow with high exhaust grilles.
2. The space within 18 inches of the ceiling must be clear of electrical hazards if continuous ventilation is not provided.
3. Installation of automatic fire protection sprinkler systems if not currently existing.
4. Area separation by noncombustible walls and ceilings.
5. Hydrogen detection systems installation.
6. Removal of heating equipment with open flames or surface temperatures in excess of 750°F. This may require suitable replacement heating systems.
7. Standby power for safety systems such as mechanical ventilation and gas detection systems.

Figure 5. *Typical configuration of hydrogen storage/equipment station.*

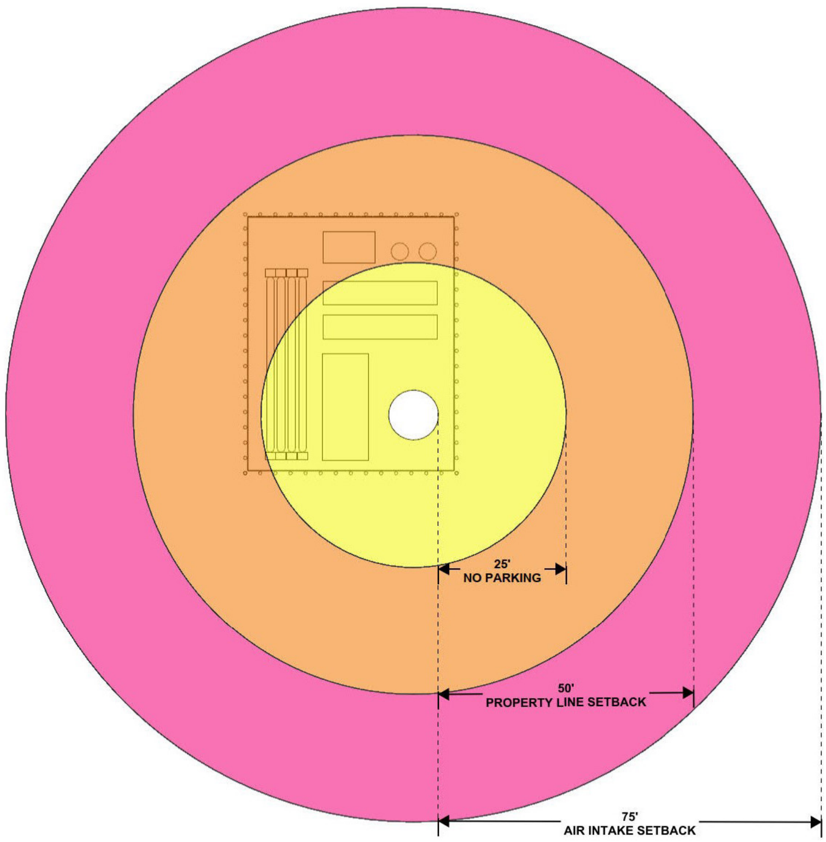
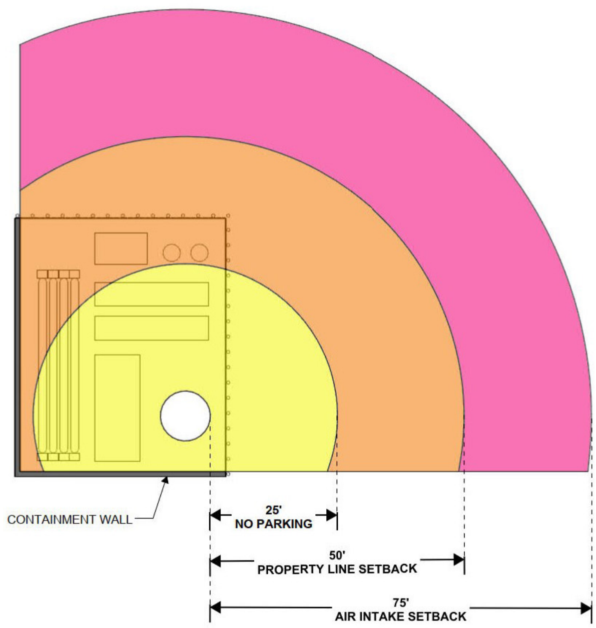


Figure 6. *Typical configuration of hydrogen storage and equipment station with required setbacks shown, illustrating effect of containment walls.*



The liquid hydrogen is to be kept in an outdoor aboveground storage tank. The required setback distance for the liquid storage tank - from property lines, parked vehicles, and air intake openings in buildings - varies depending on the storage tank size, and the type of exposure. The required minimum distance from outdoor bulk liquid hydrogen to the various classes of exposures can be found in **Appendix B, Exhibit 3.4**. The Allegheny and Callowhill facilities cannot store liquid hydrogen on site due to a lack of outdoor space for the tankage and required setbacks. Set back requirements can significantly impact available siting of hydrogen equipment even at facilities with outdoor space and may reduce effective facility parking capacity.

In some cases, setback requirements can be reduced via the use of fire barrier containment walls around up to three sides of the hydrogen storage and equipment yard.

A number of these requirements, such as the installation of automatic fire suppression sprinklers, will be advantageous

1 Full extent of facility considerations can be found in **Appendix B**.

for both FCEBs and BEBs. At this time, there are no prescriptive standards for fire prevention and suppression systems in facilities that store BEBs. However, it is likely that when standards are written for indoor storage of BEBs they will require higher sprinkler water volumes than are currently required for gasoline or diesel vehicles.

SEPTA HYDROGEN FUELING REQUIREMENTS

Used in a fuel cell, hydrogen combines with oxygen from the air to directly produce electricity without generating any pollution at the point of use: water and heat are the only byproducts. Hydrogen fuel can either be generated on-site or trucked to the depot facilities. Due to associated electrical and spatial requirements, On-site generation of hydrogen fuel via electrolysis has been deemed unfeasible at all eight depots for a full fleet implementation due to the significant associated electrical and spatial requirements. The required production and storage level of full-scale on-site electrolysis would require SEPTA to acquire urban private property and risks increasing project impacts that the public could perceive as negative, so this option was not considered further for this report.

Hydrogen can be transported and stored in either its gaseous or liquid form. While the FCEBs will consume the hydrogen in gaseous form, the hydrogen would be delivered and stored as a liquid. Delivery of liquid hydrogen reduces the necessary tank size and number of required deliveries since liquid hydrogen is eight times denser than compressed gaseous hydrogen at 5,000 psi pressure.

The Air Liquide LM-XL-35 Station has been used as the design basis for developing the conceptual designs presented in this report. Typical of the commercially available systems on the market, the modular nature of this station provides flexibility for equipment placement and scalability. This station design is available in multiple sizes to accommodate bus fleets ranging from 10 to 50 buses and offers capability to increase fueling capacity as the FCEB fleet grows. The station standard equipment includes: an 18,000-gallon liquid hydrogen storage tank, two pumps, two dispensers, and gaseous buffer storage to support bus fueling at a rate of up to 150 kilograms per hour per dispenser. For this report, a 15,000-gallon tank has been used in the design for all depots since the consumption analysis determined that the larger tank was not required.

The forecasted hydrogen use by depot was calculated based on the current volume of diesel fuel consumed daily at each facility, adjusted based on relative energy content and the difference in average efficiency between diesel and fuel cell engines. Across the eight depots analyzed within the scope, an estimated 23,429 kilograms of hydrogen is required daily system-wide to fuel FCEBs that would provide current service levels on existing SEPTA routes. The forecasted number of weekly hydrogen fuel deliveries at each facility is consistent with the current frequency of diesel fuel deliveries, based upon calculated daily hydrogen fuel use and typical hydrogen tanker volume; thus, the liquid hydrogen delivery schedule should not impact facility operations.

The required amount of hydrogen fuel and tank sizing for each depot has been calculated using the equations shown in **Appendix E**, and results have been summarized in **Tables 2 and 3**. These values have been used to develop the conceptual hydrogen fueling designs for each depot shown in **Appendix D**.

Table 2. Hydrogen demand

Depot	Hydrogen Use[1,4]					
	AVG/bus/day kg	Total/day kg	Peak Hour[2] kg/hr.	Avg Hour[3] kg/hr.	Number of 15,000 gal. Storage Tanks	Minimum Deliveries per Week[4]
Midvale	24.3	5,191	1,601	519	3	10
Allegheny (satellite)	25.9	2,276	491	228	1	5
Comly	21.3	2,659	553	266	2	5
Frankford	15.5	1,878	388	188	1	4
Victory	24.0	2,902	624	290	2	6
Callowhill (satellite)	21.1	2,978	655	298	1	6
Southern	23.4	3,370	725	337	2	7
Frontier	26.8	2,174	456	217	1	4

Table 3. Hydrogen equipment required

Depot	Hydrogen Fueling[3]		# of Required Stations	# of Required Dispensers	Days H_2 Storage [4]
	Buses / hour	kg / hour			
Midvale	22	534	3	4	1.56
Allegheny (satellite)	9	233	1	2	1.19
Comly	16	341	2	3	2.03
Frankford	16	249	1	2	1.44
Victory	16	384	2	3	1.86
Callowhill (satellite)	18	381	1	2	1.15
Southern	18	422	2	3	1.60
Frontier	11	296	1	2	1.24

[1] Fuel Energy Content

	Energy (HHV)	Engine Efficiency	Usable Energy
Diesel Fuel	138,490 BTU/gal	35%	48,472 BTU/gal
Hydrogen Fuel	134,785 BTU/KG	50%	67,393 BTU/KG

[2] Assumes all buses fueled as they come off the road. Only Allegheny must be sized to peak hour, other depots sized to average hour

[3] Assumes: 8 hours to fuel all buses at Comly, Frankford, Victory, Callowhill (satellite), Southern, and Frontier, 10 hours to fuel all buses at Midvale and Allegheny (satellite).

[4] 15,000-gallon Liquid H_2 tanker volume = 2,700 kg (usable) H_2

	15,000 gal. Tank
Max Liquid Storage (kg)	2,700
Max Dispensers Per Station	2
Max H_2 Per Dispenser (kg/hr.)	150

Figure 7. Bus Parking at Midvale

The values in **Tables 2 and 3** can be illustrated using Midvale as a case study. Midvale will require over 5,000 kilograms of hydrogen per day to fuel FCEB operating current service levels - nearly 9 million annual miles traveled. Both of these values are the largest respective totals among the eight SEPTA bus depots. Currently, each bus assigned to Midvale uses an average of 33.7 gallons of diesel fuel per day. Applying the same method to the energy efficiency of hydrogen fuel (Eq. 3), this means that each FCEB operating out of Midvale will, on average, require 24.3 kilograms of hydrogen per day, for a total daily demand of 5,191 kilograms of hydrogen per day at this facility. This translates to a 30,000-gallon fuel tank, which will provide 4% excess of the daily fuel requirements. However, multiple tanks with a smaller capacity could be used in lieu of a single 30,000-gallon tank.

Using Midvale as a satellite FCEB fueling location for the current Allegheny fleet would add 2,276 kilograms of daily hydrogen demand, calculated using the same method detailed above. The Midvale depot has ample space for the additional equipment. Midvale will require three LM-XL-35 tanks to support the currently assigned fleet (four tanks required for Allegheny satellite option).

Similarly, Callowhill lacks the space needed for on-site hydrogen storage or dispensing but its fleet could potentially fuel two miles away at Victory. Victory will require 2,902 kg of hydrogen daily to fuel its current fleet and 5,879 kg of hydrogen daily to fuel both its fleet and the Callowhill fleet under a satellite fueling scenario.

CONCEPTUAL HYDROGEN FUELING DESIGNS AT SEPTA FACILITIES

To develop conceptual hydrogen fueling designs at each SEPTA depot, the WSP Team used the Air Liquide Liquid Bus Station LM-XL-35 configuration as the basis of design. The system includes a vertical liquid tank (a 15,000 gallon tank was used for this analysis), a liquid pump skid, valve skids with vaporizers, nitrogen tanks (for purging and instrument gas), a compressor, and gaseous buffer storage cylinders within a 40’5” by 49’9” footprint (see **Figure 7**) . This modular system is typical of commercially available systems for fueling transit buses and other heavy-duty FCEBs.

Figure 8. *Liquid H_2 Station, LM-XL-35 Configuration. Footprint does not include dispenser islands, fueling pad, or electrical utilities.*

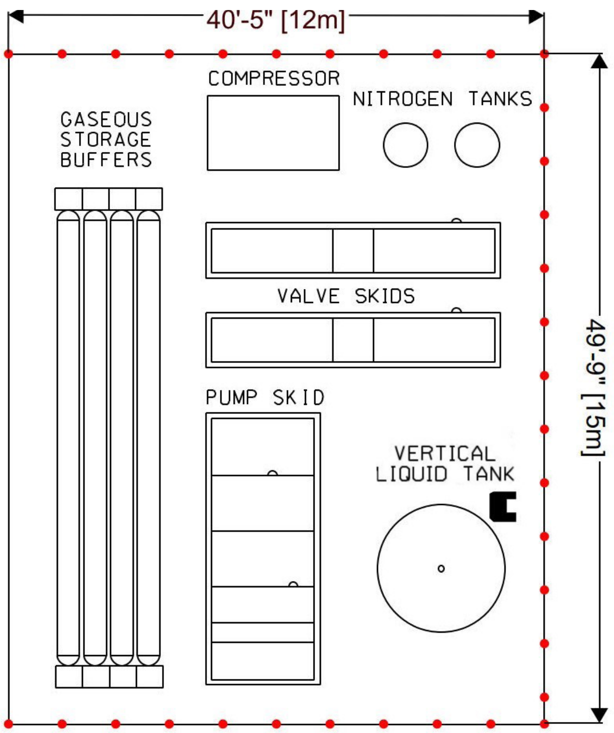


Table 4. Hydrogen fueling site impacts

Depot	Location on H_2 Station Site	Footprint of H_2 Station (s)	Approximate # of Bus Parking Spaces Impacted	Approximate # of Employee Parking Spaces Impacted
Midvale	Eastern Property Line	6050 SF	0	25-30
Allegheny (satellite)	Eastern Property Line	2000 SF	0	0-5
Comly	Southeastern Property Line	4200 SF	0-5	20-25
Frankford	Southern Corner	2110 SF	0-5	0
Victory	Northern Property Line	4030 SF	5-10	0
Callowhill (satellite)	Northern Property Line	2020 SF	0-5	0
Southern	Southeast Corner	4030 SF	0-5	0
Frontier	South of Fueling Building	2110 SF	0	0

Table 5. Conceptual connected load

Depot	Existing Connected Load	Number of H_2 Stations[1]	Additional Connected Load of H_2 Stations	Total Connected Load	Conceptual Electrical Capacity Needs Met
Midvale	800 kW	3	1050 kW	1850 KW	YES
Allegheny (satellite)	N/A	1	350 KW	350 KW	YES
Comly	227 kW	2	700 kW	927 KW	YES
Frankford	375 kW	1	350 KW	725 KW	YES
Victory	325 kW	2	700 KW	1025 KW	NO, REQUIRES UPGRADE
Callowhill (satellite)	N/A	3	350 kW	350 kW	NO, REQUIRES UPGRADE
Southern	300 kW	2	700 KW	1000 KW	NO, REQUIRES UPGRADE
Frontier	160 kW	1	350 KW	510 KW	YES

[1] Fuel Energy Content

The LM-XL-35 station can deliver up to 300 kg/hr. of hydrogen via two dispensers, with 2,700 kg of usable hydrogen storage in the 15,000-gallon vertical tank. As noted above, SEPTA FCEB buses are estimated to use 20-26 kg/day of hydrogen each. Therefore, one LM-XL-35 station can provide 8-10 minutes fills to two buses simultaneously and can fuel 95 – 120 buses in an 8-hour fueling window.

To support a 100% FCEB fleet, Frankford and Frontier would each require one LM-XL-35 station, while Comly, Southern, and Victory would each require two LM-XL-35 stations, and Midvale would require three (see **Table 3**). The Allegheny at Midvale and Callowhill at Victory satellite options would each require one additional LM-XL-35 station, for a total of 13 stations among the six existing bus depot facilities to serve a 100% FCEB fleet system-wide.

None of SEPTA's eight bus depots have sufficient existing space for new outdoor hydrogen fueling lanes without significantly reducing bus parking capacity or negatively impacting site circulation patterns (unless diesel fueling lanes are decommissioned and existi8jg fueling building demolished). As such, the conceptual hydrogen fueling designs at all locations assume that hydrogen fuel dispensers will be installed in the existing fueling building, in the vicinity of existing diesel fuel dispensers.

The proposed location of the hydrogen storage/equipment compound at each site was based on the following:

» Minimize cost of trenching and piping by locating as close as possible to existing fueling lanes.
» Comply with minimum code required setbacks from property lines and building openings.
» Minimize impacts on bus parking areas and site circulation.

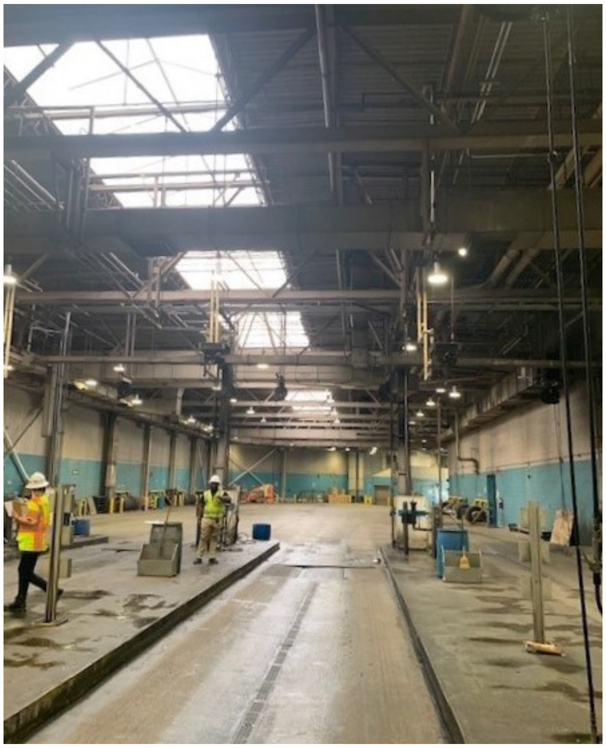
At some depots a small amount of existing bus parking is lost or displaced to another location on the site to accommodate the hydrogen storage and fueling equipment. In most cases these displaced buses can be parked elsewhere on the property or relocated to existing crush (overflow) parking.

Table 4 includes a summary of the conceptual hydrogen fueling design impacts as shown in the site layouts in **Appendix C**.

Proposed Site Designs

Throughout this analysis, eight of the existing SEPTA bus depots were considered for liquid hydrogen storage and fueling. Given the age, size and location of the facilities, introduction of either FCEBs or BEBs will require facility improvements to accommodate either type of zero-emission bus technology. The large footprint and unused space at both Midvale and Frontier depots make these great contenders for implementing FCEBs. The tight configurations at Callowhill and Allegheny depots - which each occupy a full city block from sidewalk to sidewalk - makes on-site hydrogen fueling difficult, though satellite fueling solutions are available for each as presented herein. Though there are some constraints, solutions exist to implement FCEBs throughout SEPTA's full fleet.

Figure 9*. Fueling lane at Midvale, looking toward revenue vault*



At **Midvale**, the liquid hydrogen fuel tank is proposed on the grass along the east side of the property, to the south of the CHP building. This placement complies with the setback property line and building opening setback requirements and will not require containment walls to protect against potential impacts of the hydrogen storage tank. This hydrogen station placement will relocate several dozen employee parking spots to elsewhere at the facility. A secondary design for Midvale investigates the same placement of the hydrogen storage tank, but with increased capacity to fuel the buses assigned to both Midvale and Allegheny. The same impacts are to be considered in this case.

The **Allegheny** depot is located just 1.5 miles to the southwest, making satellite fueling at Midvale a feasible solution for the Allegheny fleet. This scenario involves placing one additional liquid hydrogen storage station along the east side of the Midvale property, accompanied by two outdoor dispensers beneath a canopy. This solution will not further impact any parking or site circulation.

Several options were analyzed for the location of a permanent liquid hydrogen storage station at the **Comly** bus depot facility. One option is to place the tank on the southeastern side of the facility, which will impact the existing employee parking area and require relocation of the revenue vault. The impact to employee parking can be mitigated by reorienting the revenue vault for buses to return from service at the apron on Bustleton Avenue. This placement will require containment walls to protect the depot structure, as the distance from the building is not sufficient for the required setbacks. This option is shown in the Comly conceptual design drawing and cost estimate.

Another option uses an undeveloped parcel of land to the south of the **Comly** depot. This parcel is on the 6000 block of Bustleton Avenue bound by Penn Street, Comly Street, and Bustleton Avenue. Placing the hydrogen fuel tank on this parcel would ensure that the tank is set back a sufficient distance from the building, though this would require the de-mapping of Penn Street by the City. This option provides clear access to the tank and does not require containment walls to protect the depot structure, nor would this impact existing employee parking or bus circulation.

At the nearby **Frankford** bus depot, the facility is situated alongside the Frankford Transportation Center. The transportation hub has numerous bus stops and elevated light rail lines along the eastern side of the depot. Additionally, much of the facility's footprint and surrounding streets are beneath an overhead catenary structure, which serves the rubber wheeled trollies that are also housed at this depot. With these considerations, the proposed location for the liquid hydrogen storage tank is in the southernmost corner of the site; given that this corner of the site is adjacent to outdoor passenger waiting areas and elevated rail lines, containment walls will be required to protect these features.

The **Victory** bus depot is situated between Cobbs Creek and SEPTA owned rail lines on Victory Avenue in Upper Darby, Pennsylvania. The proposed location of the hydrogen liquid storage is along the northern boundary of the property, which borders Cobbs Creek. Containment walls will be required due to proximity to the existing fueling building. The area between these proposed stations and the fueling building is sufficient to serve as a bypass lane to mitigating any impacts to depot circulation.[2]

The Victory depot can be equipped to support fueling needs for the **Callowhill** fleet, as this facility is located less than 2 miles away. This proposed plan would situate a third liquid hydrogen storage station along Cobbs Creek, to the east of the initial stations. Fuel dispensers tied to this station , would be beneath a canopy, eliminating the need for additional retrofits. The canopy and dispensers will be located to the east of this third station, eliminating potential impacts to depot circulation,

The **Frontier** depot is able to locate a permanent liquid hydrogen storage tank at the rear western corner of the lot without losing any parking capacity, as the down-line parking is able to be relocated without creating further impacts to the site.. A containment wall will be required along one side of the hydrogen storage station in order to comply with the property setback requirement. Frontier is a great contender for FCEBs due to the operating range provided and the lengthy suburban routes served out of this facility.

Finally, the **Southern** bus depot occupies a space in South Philadelphia equivalent to approximately two city blocks; the southeastern corner of the site is the best location for a hydrogen storage tank at this facility. Placing the tank here follows property line setback requirements through the use of containment walls but requires reorientation of the revenue vault to comply with the building air intake setback requirements. A containment wall will be required in order to mitigate any impact to the neighborhood.

All depots discussed above will require the facilities to be retrofitted with the installation of 2-hour rated fire walls around the fueling lanes, or the fueling building, to protect the remainder of the facility from potential impacts. Site layouts of the six depots where it is possible to place a hydrogen storage tank are shown in **Appendix C**.

The only modification to the interior fueling islands is installing hydrogen fuel dispensers, although the area surrounding the fueling lanes will require mechanical exhaust upgrades and a hydrogen safety system. This safety system is to be comprised of gaseous hydrogen sensors, flame detection cameras, and automated roll down doors. The automated rolldown doors will be triggered in the event that one of the hydrogen sensors or flame detection cameras indicates that there is a hydrogen leak. Interior 2-hour rated fire doors will be located at the end of the fuel islands.

Table 6 shows the estimated cost of hydrogen fueling infrastructure for each of the six facilities plus the additional two satellite fueling scenarios for Allegheny and Callowhill. The estimated total cost for these improvements is $71.4 MM. Detailed cost estimates for each facility are included in **Appendix D**.

2 This option was not shown in the drawings or cost estimate due to the need for right-of-way acquisition.

Table 6. Cost Estimate Summary

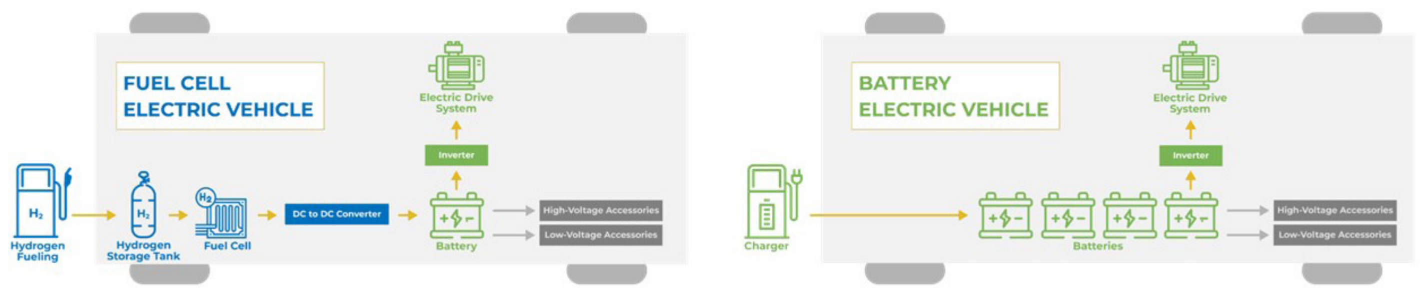
	Midvale	Allegheny (satellite)	Comly	Frankford	Victory	Callowhill (satellite)	Southern	Frontier
Estimated Cost	$16.1 MM	$4.7 MM	$11.0 MM	$6.7 MM	$11.0 MM	$4.8 MM	$11.1 MM	$6.5 MM
Items Included	» Exterior upgrades and H2 equipment, including capital cost of hydrogen tank(s) » Interior upgrades to fueling lane(s) » Exterior electrical upgrades » H2 safety systems							
Items Not Included	» Retrofits to depot buildings or bays other than fueling area » Operating costs and cost of labor » Fuel Call Electric Buses » Demolition, unless stated otherwise » Operating costs » Relocation of revenue vaults at Comly and Southern » Impacts to stormwater management facility at Southern » Interior electrical upgrades							
Assumptions	» Interior H_2 piping to use raised infrastructure to avoid trenching in existing floor » Agency to purchase rather than lease hydrogen storage tanks » Proposed fueling lane interior walls to have 2-hour fire rating » 20% Cost Contingency							

COMPARISON OF BATTERY BUS CHARGING AND HYDROGEN FUELING

BEBs are powered by on board batteries, which are charged either on route or at a bus depot. These chargers can vary by location, power type, power level, and power transfer method. The selected charging methods should maximize the operating range of the bus and minimize impacts to SEPTA facilities, while efficiently using staff time.

FCEBs and BEBs are similar in that the motor is directly powered by a battery; however, an FCEB has a much smaller battery than a BEB. An FCEB's battery is continuously "recharged" by electricity generated by a fuel cell engine using the onboard compressed hydrogen gas.

Figure 10. Diagram of BEB and FCEB power systems. (Source: Zero-Emission Bus Resource Alliance)



Numerous factors differentiate FCEBs from BEBs. BEBs currently have a lower upfront cost than FCEBs, though they have a shorter operating range than FCEBs. Hydrogen FCEBs utilize an on board fuel cell to generate the electricity required to charge the on board battery, which in turn will power the motor. Compared to BEBs, FCEBs offer reduced fueling times along with a longer range between charging/fueling events, and energy use (kg/mi) is not significantly impacted by extreme temperatures as is the case with BEBs. The only tailpipe emission from an FCEB is water vapor.

COST COMPARISON: BATTERY vs. FUEL CELL ELECTRIC BUSES

Table 7. *Comparison of BEBs and FCEBs.*

	Cost Estimate Subtotals		Additional Connected Load Subtotals	
Depot	**BEB Fleet Charging Infrastructure**	**FCEB Fleet H_2 Fueling Infrastructure**	**BEB**	**FCEB**
Midvale	$51.9 MM	$16.1 MM	15840 kW	1050 kW
Allegheny (satellite)*	$25.1 MM	$4.5 MM	6120 kW	350 kW
Comly	$30.0 MM	$11.0 MM	7200 kW	700 kW
Frankford	$21.5 MM	$6.7 MM	6300 kW	350 kW
Victory	$27.5 MM	$11.0 MM	6120 kW	700 kW
Callowhill (satellite)*	$27.9 MM	$4.5 MM	9180 kW	350 kW
Southern	$34.5 MM	$11.1 MM	9720 kW	700 kW
Frontier	$31.5 MM	$6.5 MM	5940 kW	350 kW
Total	**$249.5 MM**	**$71.4 MM**	**66420 kW**	**4550 kW**

* FCEB cost estimates for Allegheny and Callowhill fueling are costs to add capacity at Midvale and Victory, respectively, to allow for satellite fueling of Allegheny and Callowhill buses at these depots.

The FCEB Fleet cost estimates at each depot shown in **Table 7** account for purchase and installation of the hydrogen storage facility, indoor hydrogen fueling stations, and electrical upgrades. The cost of FCEBs and additional site modifications within the depot maintenance and parking areas to comply with hydrogen related codes and standards are not included.

The BEB cost estimate figures were taken from the SEPTA Forward ZEB Playbook Appendix F, and were not independently verified by WSP under this project. Total costs shown for a BEB Fleet are the estimated cost of charging infrastructure required to accommodate a 100% electric bus fleet at the depot. Similarly, total FCEB Fleet costs are estimated costs to construct hydrogen storage and fueling capacity sufficient to serve a 100% FCEB fleet at the depot.

Both FCEB fueling and BEB charging will require additional electrical capacity at the depot. The estimated additional connected load for 100% BEB and FCEB fleets are shown in the last two columns of **Table 7**. For BEB fleet these values are based on the estimated number of 180 kW and 450 kW chargers required at each depot, as shown in the SEPTA Forward ZEB Playbook, Appendix F. For FCEB fleet this is based on the estimated number of hydrogen stations required to serve a 100% FCEB fleet at each depot and an estimated connected load or 350 kW/station, per manufacturer specifications.

For FCEB fueling it is expected that all hydrogen dispensers at any given depot will be in operation simultaneously during peak fueling operations, so the connected load shown in **Table 7** will approximate monthly peak electrical load from fueling operations.

APPENDIX A

EXISTING FACILITY CONDITIONS

DEPOT:	MIDVALE	Location:	4301 Wissahickon Ave
BUS ASSIGNMENT:	40-ft 245	60-ft 62	Special notes: None

SUMMARY:	Bus depot facility is bounded by SEPTA owned ring road on three sides and a private business on the fourth. There is a CSX rail line adjacent to the ring road on east side of property. Depot facility includes a fueling building adjacent to a maintenance building, with the majority of bus parking under an open canopy structure next to the maintenance building. There is a small area of outdoor bus parking at south end of parking structure. SEPTA-owned site includes an 8 MW CHP facility, a small grass area along east side, paved employee parking in front of the CHP building, and a gravel lot used for dead bus and other storage to the North of CHP building. There are two entrances to the site ring road from Wissahickon Avenue, used for bus and non-bus traffic.

DEPOT DAILY SERVICE CYCLE
Sometimes bus operator pulls bus through servicing directly, but mostly BO parks bus then a shifter moves it through service later. Farebox vault is in front of fuel island, and exterior bus wash is behind fuel island, so the process is: 1) drop farebox, 2) add fuel and fluids, 3) exterior wash, 4) park bus, and 5) interior cleaning (in parking area, not in fueling area). Shifters work all three shifts.

DEPOT FUELING FACILITY			
Location on site:	Separate building to east of maintenance bays and parking building.		
# Fueling lanes	3 + bypass lane	Dispensers/lane	2
Overhead structure type & lighting	Open web joists. Lights are more than 18 inches below ceiling. There are open flame heaters, but they are more than 18 inches below ceiling.		
In-ground tank location	To east of fuel building next to electrical/boiler room		
Location of farebox vault	Ahead of fuel island in fueling building		
Location of interior cleaning	In bus storage area		

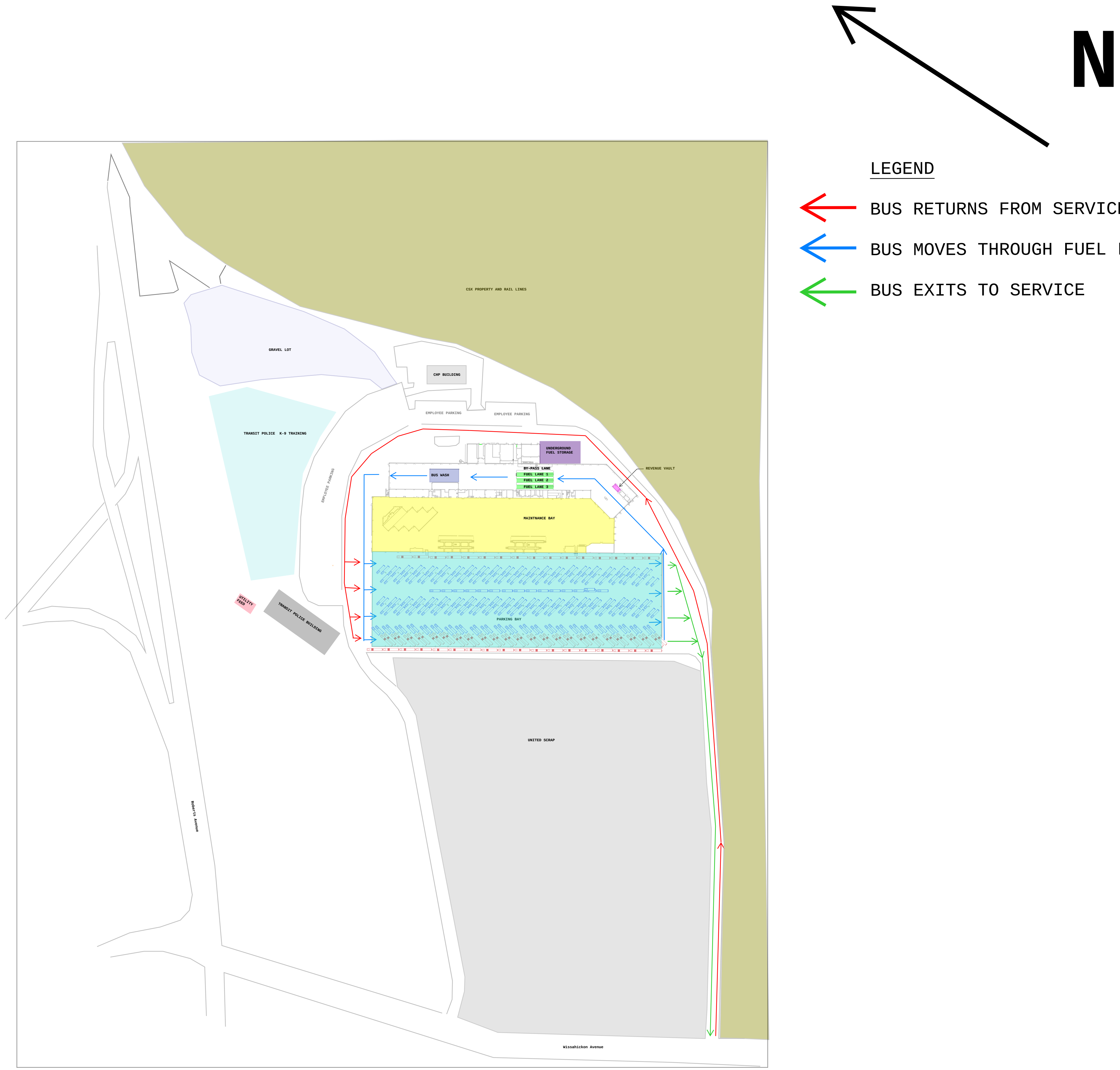
SITE CIRCULATION	
Bus Entrance	Enter site from Wissahickon Avenue south of building, loop around east side of building and enter parking structure at North end

Bus Exit	Exit South end of parking structure, turn right, then right onto Wissahickon Avenue
Non-bus Entrance	Same as bus, or can enter from Wissahickon Avenue to North of building
Non-bus Exit	Loop around east side of building and exit as buses do
Circulation path for fueling buses Parking – fueling - parking	Enter parking building from North. Exit parking to south, loop around south end of building to enter fueling lanes going south to north. Exit fuel lane and turn left past maintenance bays and enter parking structure going north to south
Circulation path exiting buses	Exit South end of building, turn right, then right onto Wissahickon Avenue

INTERIOR BUS PARKING AREA	
Overhead Structure	Canopy structure with open sides. Roof structure is open web joists. Buses are parked on an angle rather than in linear tracks.
Emission sources w/in 18 inches of ceiling? Y/N	Conduit and lights within 18 inches of ceiling. No open flame heaters

OTHER:

- Bus storage is under a canopy with open sides – buses are parked at an angle rather than in linear tracks
- Dead bus storage in SEPTA owned gravel lot to north of CHP building
- Existing utility feed and transformers at northeast corner of site. Feed is at 13.2 kV, with 480 V transformers on SEPTA property.
- There is a small grass area to south of CHP building
- There is paved employee parking to south of CHP building
- A CSX rail line runs directly along the south side of the site



LEGEND

BUS RETURNS FROM SERVICE TO PARKING

BUS MOVES THROUGH FUEL LANE TO PARKING

BUS EXITS TO SERVICE

DEPOT:	Allegheny	Location:	2500 W Allegheny Avenue
BUS ASSIGNMENT:	40-ft 47	60-ft 81	Special notes: Urban location with no outdoor space. 1.6 miles from Midvale Depot

SUMMARY:	Bus depot occupies a full city block, with a single building covering virtually the entire site from sidewalk to sidewalk. There are row houses across the street on all four sides. The only paved outdoor space is a small apron at bus entrance/exit onto West Allegheny Street. All depot activities, including all bus circulation happen within the building envelope

DEPOT DAILY SERVICE CYCLE
Typically, the bus operator pulls bus through fueling and servicing when coming out of service then parks it, even during peak pull in. Farebox vault is in front of fuel island, and exterior bus wash is behind fuel island, so the process is: 1) drop farebox, 2) add fuel and fluids, 3) exterior wash, 4) park bus, and 5) interior cleaning (in parking area, not in fueling area).

DEPOT FUELING FACILITY			
Location on site:	First bay in building, closest to 27th Street. Enter off Allegheny Avenue		
# Fueling lanes	2 + bypass lane	Dispensers/lane	1
Overhead structure type & lighting	Open web joists. Lights are more than 18 inches below ceiling. There are no open flame heaters.		
In-ground tank location	Under sidewalk on 27th Street		
Location of farebox vault	Ahead of fuel island in fueling building		
Location of interior cleaning	In bus storage area		

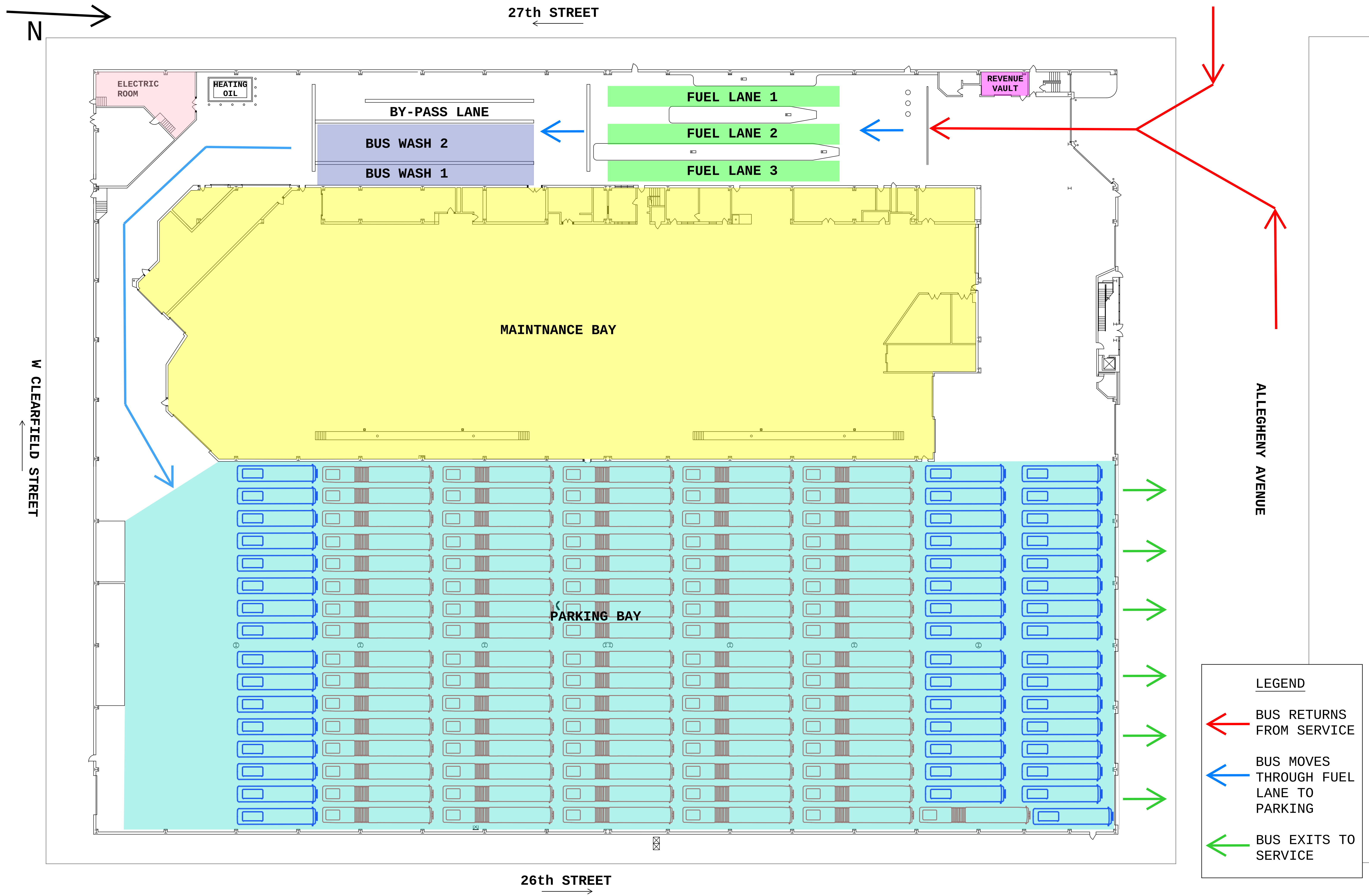
SITE CIRCULATION	
Bus Entrance	Returning buses enter building from Allegheny Avenue, through fuel lane entrance
Bus Exit	Buses exit from bus parking lanes onto Allegheny Avenue
Non-bus Entrance	NA
Non-bus Exit	NA

Circulation path for fueling buses Parking – fueling - parking	Enter fueling lane from Allegheny Avenue, loop around maintenance area on internal circulation path to bus parking lanes.
Circulation path exiting buses	Exit from bus parking lanes onto Allegheny Avenue

INTERIOR BUS PARKING AREA	
Overhead Structure	Open web joists. Buses parked on linear tracks.
Emission sources w/in 18 inches of ceiling? Y/N	Conduit and lights within 18 inches of ceiling. No open flame heaters

OTHER:

- Building occupies full city block. No paved area except short apron on Allegheny Avenue side
- Utility service enter building at corner of N 27th Street and W Clearfield St. Feed is at 13.2 kV, with 480 V transformers on SEPTA property.



N
27th STREET
ELECTRIC ROOM
HEATING OIL
BY-PASS LANE
BUS WASH 2
BUS WASH 1
FUEL LANE 1
FUEL LANE 2
FUEL LANE 3
REVENUE VAULT
MAINTNANCE BAY
PARKING BAY
W CLEARFIELD STREET
ALLEGHENY AVENUE
26th STREET
LEGEND
BUS RETURNS FROM SERVICE
BUS MOVES THROUGH FUEL LANE TO PARKING
BUS EXITS TO SERVICE

SEPTA SITE VISIT SUMMARY 7/12 – 7/13, 2022

DEPOT:	VICTORY	Location:	110 Victory Ave
BUS ASSIGNMENT:	40-ft 145	60-ft 0	Special notes: High priority for FCEB due to assigned suburban routes with high daily energy demand

SUMMARY:	The Victory Depot consists of a maintenance building, a separate fuel/wash building, and outdoor bus parking on horizontal tracks. The site is bounded by Cobbs Creek to the North, SEPTA light rail tracks to the South and West, and Victory Avenue to the East. The site also includes a paint shop and is connected to a gravel storage area adjacent to the light rail tracks to the West.

DEPOT DAILY SERVICE CYCLE
Bus operators drop the farebox vault then park buses in the parking area, and later shifters move them through fueling and interior and exterior wash. Interior cleaning happens in the fuel lane during fueling. Shifters work all three shifts.

DEPOT FUELING FACILITY			
Location on site:	Separate building to the North of depot site parallel to edge of property.		
# Fueling lanes	2	Dispensers/lane	2 + 1; three total
Overhead structure type & lighting	Open web joists. Lights and conduit at ceiling level. Electric heater that is more than 18 inches below ceiling.		
In-ground tank location	To North of fuel building and to South of Paint shop		
Location of farebox vault	At Northwest corner of maintenance building		
Location of interior cleaning	In fuel lane		

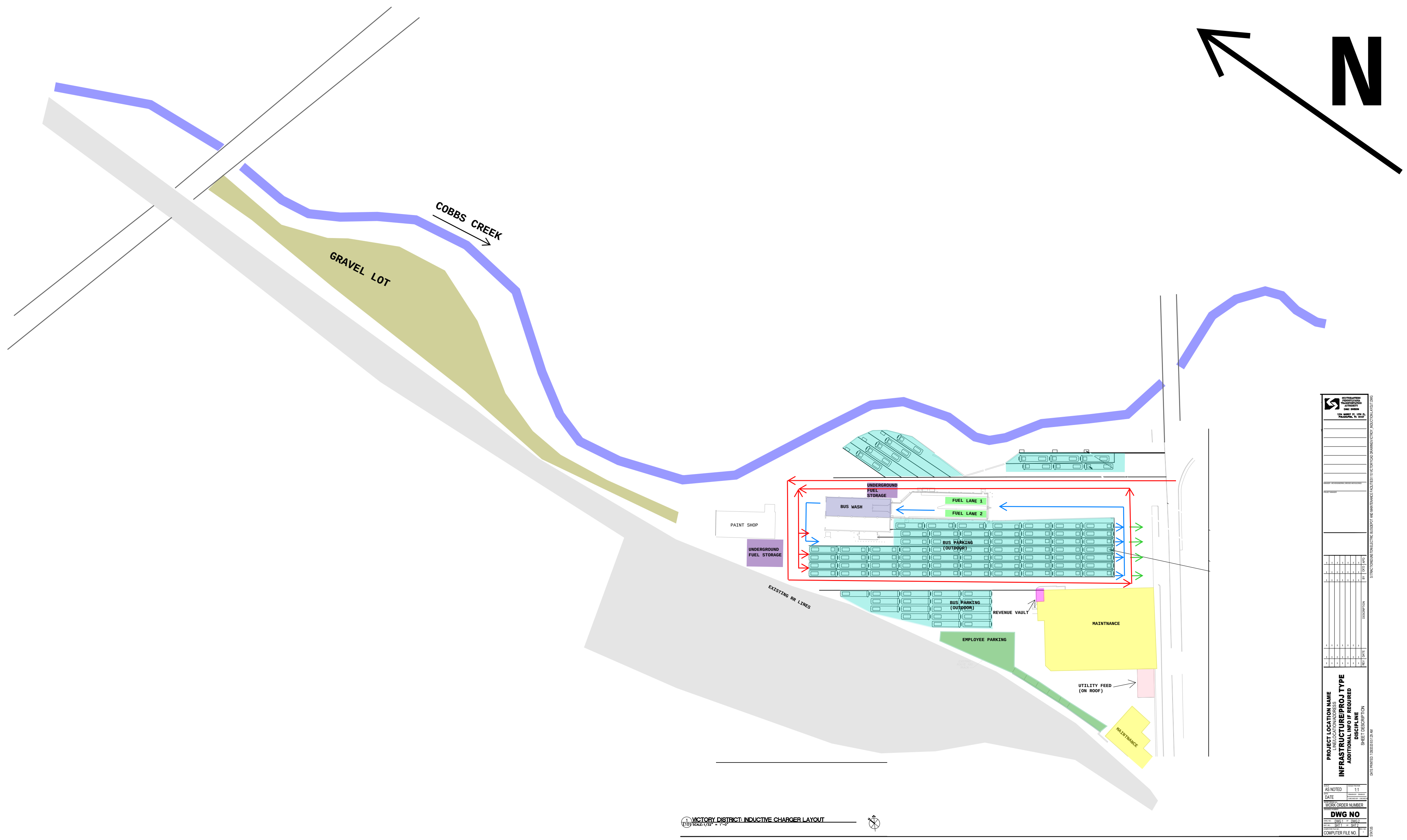
SITE CIRCULATION	
Bus Entrance	Enter site from Victory Avenue, drive to North of fuel building and loop South to bus parking area
Bus Exit	Exit straight onto Victory Avenue from Bus Parking Area
Non-bus Entrance	Same as bus
Non-bus Exit	Same as bus

Circulation path for fueling buses Parking – fueling - parking	From parking area turn left and head West to fuel building. When exiting fuel building turn left then left again to enter parking tracks
Circulation path exiting buses	Exit straight onto Victory Avenue

INTERIOR BUS PARKING AREA	
Overhead Structure	Not applicable – all bus parking outdoors
Emission sources w/in 18 inches of ceiling? Y/N	N/A

OTHER:

- Existing utility feed and transformers are on top of maintenance building adjacent to Victory Avenue. Feed is at 13.2 kV, with 480 V transformers on building roof.
- All bus storage outdoors in linear tracks
- Paved area to North of fuel building could be used for H2 infrastructure
- Site has direct access to a gravel lot used for miscellaneous storage which is West of the paint shop next to light rail tracks
- There is a large employee parking lot across Victory Avenue from the depot



LEGEND

- BUS RETURNS FROM SERVICE TO PARKING
- BUS MOVES THROUGH FUEL LANE TO PARKING
- BUS EXITS TO SERVICE

SEPTA SITE VISIT SUMMARY 7/12 – 7/13, 2022

DEPOT:	Comly	Location:	6000 Penn Street
BUS ASSIGNMENT:	40-ft 148	60-ft 21	Special notes: None

SUMMARY:	Bus depot site is bounded to north, east, and west by blocks of row houses along Saul, Benner, and Comly Streets, and to the southeast by a cemetery across Bustleton Avenue. About three quarters of the site is occupied by a single building that houses the fuel and wash lane, maintenance bays, and indoor bus parking. There is also a paved area of outdoor bus parking to the northeast of the building along Benner Street. To the southeast of the building is paved employee parking along Bustleton Avenue.

DEPOT DAILY SERVICE CYCLE
Bus operators drop the farebox vault upon entering the depot site from Penn Street, bus operator pulls through the revenue vault, then park buses in the parking area, either inside or outside the building. Later, shifters move buses to the fueling area for fueling and exterior wash, then back to bus parking. Interior cleaning happens in the bus parking area after fueling. Shifters work all three shifts.

DEPOT FUELING FACILITY			
Location on site:	First bay in building, on southeast side closest to Penn Street. Enter off Comly Street		
# Fueling lanes	2	Dispensers/lane	2
Overhead structure type & lighting	Open web joists. Lights, conduit, and open flame heaters at ceiling level		
In-ground tank location	Under employee parking area between building and Bustleton Avenue		
Location of farebox vault	At southeast corner of building near entrance from Bustleton Avenue		
Location of interior cleaning	In bus parking area		

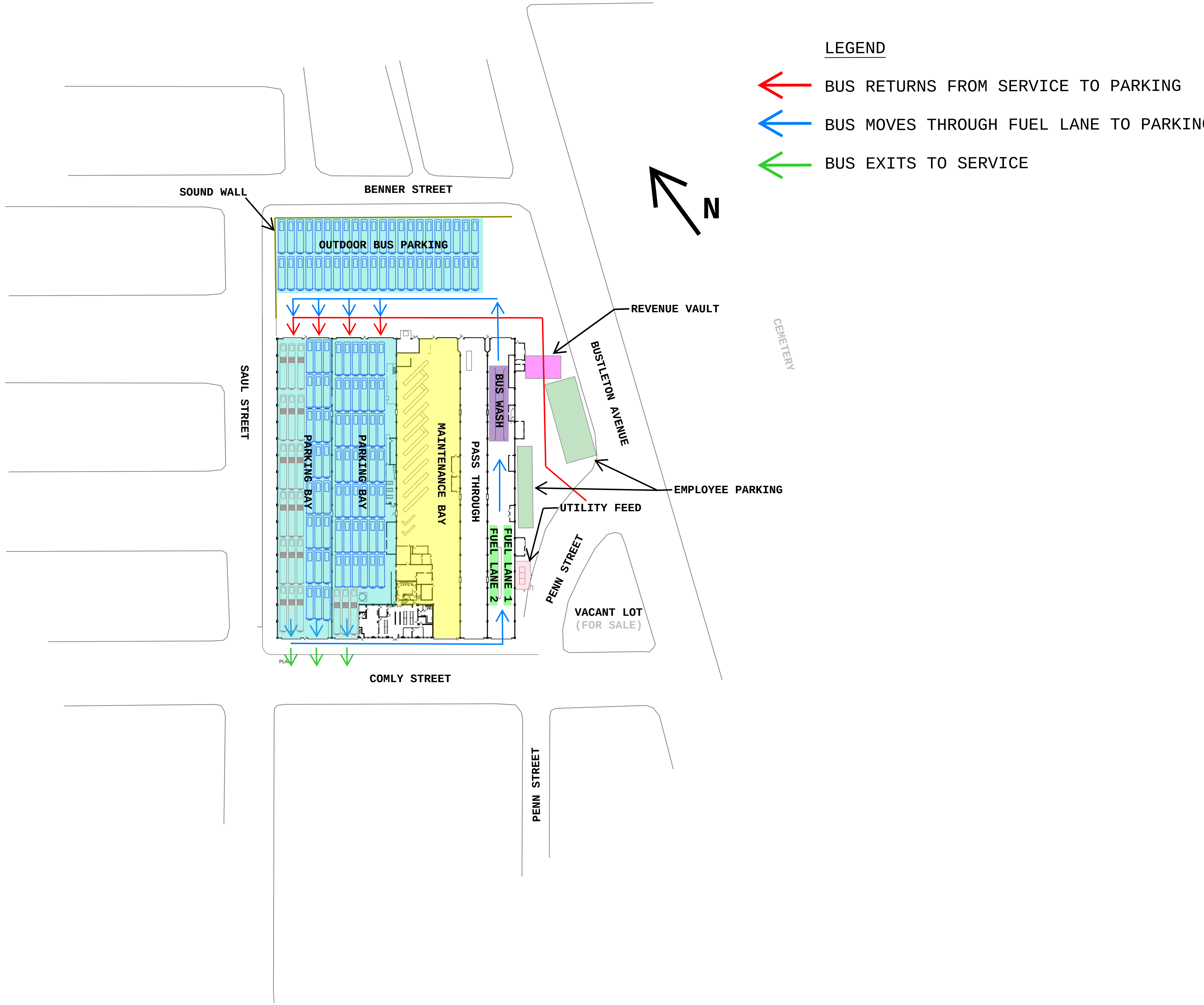
SITE CIRCULATION	
Bus Entrance	Returning buses enter site at east end of building from Bustleton Avenue, then turn left to enter parking tracks in building. If parking in outdoor parking spaces to north of building, buses back into the spaces
Bus Exit	Buses exit from bus parking lanes onto Comly Street

Non-bus Entrance	Off Bustleton Avenue
Non-bus Exit	To Bustleton Avenue
Circulation path for fueling buses Parking – fueling - parking	Exit building onto Comly Street and turn left. Turn left into fueling lane. Exit bus wash into rear parking area then turn left and left into bus parking tracks in building.
Circulation path exiting buses	Buses exit from bus parking lanes onto Comly Street

INTERIOR BUS PARKING AREA	
Overhead Structure	Open web joists. Buses parked on linear tracks.
Emission sources w/in 18 inches of ceiling? Y/N	Conduit and lights are more than 18 inches below ceiling. Open flame heaters are mounted at ceiling level

OTHER:

- Utility service is at southwest corner of building, near entrance to fuel lane. Feed is at 13.2 kV, with 480 V transformers on SEPTA property.
- There is a small triangle of land next to the site, bounded by Penn St, Comly St, and Bustleton Avenue, which is for sale
- There is a masonry sound wall along entire edge of site along Benner Street.



LEGEND
BUS RETURNS FROM SERVICE TO PARKING
BUS MOVES THROUGH FUEL LANE TO PARKING
BUS EXITS TO SERVICE
N
SOUND WALL
BENNER STREET
OUTDOOR BUS PARKING
REVENUE VAULT
BUSTLETON AVENUE
CEMETERY
SAUL STREET
PARKING BAY
PARKING BAY
MAINTENANCE BAY
PASS THROUGH
BUS WASH
EMPLOYEE PARKING
UTILITY FEED
FUEL LANE 2
FUEL LANE 1
PENN STREET
VACANT LOT
(FOR SALE)
COMLY STREET
PENN STREET

SEPTA SITE VISIT SUMMARY 7/12 – 7/13, 2022

DEPOT:	Frankford	Location:	5235 Penn Street
BUS ASSIGNMENT:	40-ft 132	60-ft 0	Special notes: Frankford also houses rubber-tired trolleys and part of the site is equipped with overhead catenary power system

SUMMARY:	Bus depot consists of a single building that houses maintenance bays, fueling lanes, and indoor bus parking. To the east of the building on the site there is outdoor parking for rubber-tired trolleys, with overhead catenary power over the parking tracks. The first few bays on the east end of the building are also dedicated to trolley maintenance, and there is a catenary-equipped pass-through lane for trolleys at the west end of the building as well. The rest of the building houses and services diesel and diesel hybrid buses. The site is bounded by roads on three sides and the Frankford Transportation Center to the south. There is a large playground across the street to the north, and houses to the east and west. There is limited pavement around the north and west sides of the building that is mostly used for site circulation, with limited space for bus parking/queuing. There is a wide concrete apron between the building and the Frankford Transportation Center which is used for bus circulation. There is a large SEPTA-owned employee parking lot across the street to the southwest.

DEPOT DAILY SERVICE CYCLE
Coming out of service bus operators park buses in the parking bays. Later shifters move the buses through fueling/service/cleaning and park them back in the parking bays. Shifters work 3 shifts

DEPOT FUELING FACILITY			
Location on site:	First bay after trolley maintenance, on east end of building.		
# Fueling lanes	2	Dispensers/lane	2
Overhead structure type & lighting	Steel girders. There are overhead lights and conduit at ceiling level but no open flame heaters		
In-ground tank location	Under apron at fuel lane entrance		
Location of farebox vault	??		
Location of interior cleaning	??		

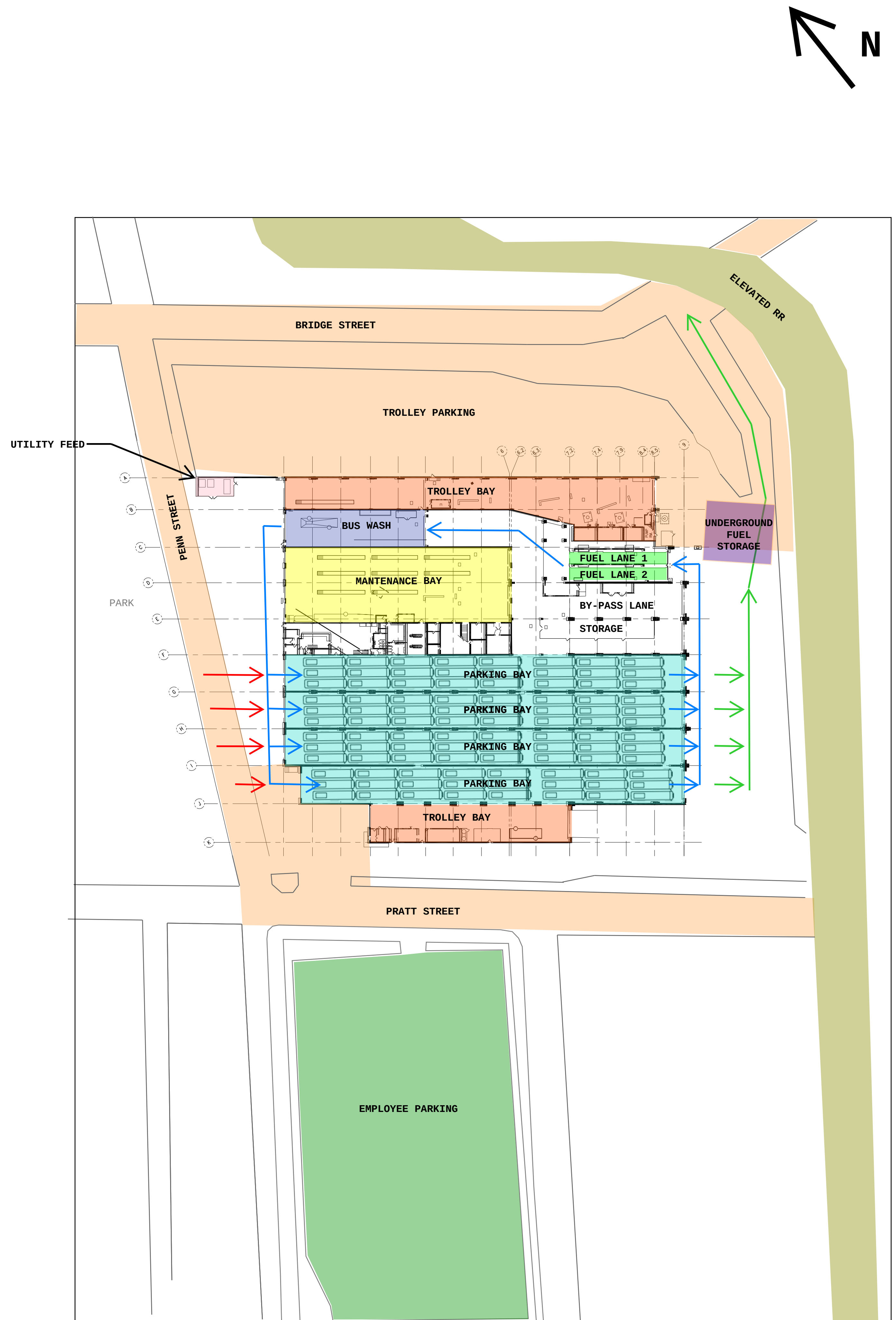
SITE CIRCULATION	
Bus Entrance	Buses enter parking bays off Penn Street

Bus Exit	Onto Bridge Street
Non-bus Entrance	Enter from Penn Street
Non-bus Exit	Exit to Bridge Street
Circulation path for fueling buses Parking – fueling - parking	Exit parking bay and turn left, then left again to enter fueling lane headed north. Exit fueling bay and turn left then left again to enter parking bays heading south
Circulation path exiting buses	Buses exit parking bays, turn left and exit the site onto Bridge Street

INTERIOR BUS PARKING AREA	
Overhead Structure	Steel girder.
Emission sources w/in 18 inches of ceiling? Y/N	There are lights and conduit at ceiling level but no open flame heaters

OTHER:

- Utility service is at northeast corner of the building. Feed is at 13.2 kV, with 480 V transformers on SEPTA property.
- There is a large SEPTA-owned employee parking lot across Pratt Street opposite the depot building.
- The east end of the site is dedicated to trolleys, with most of the west end of the site dedicated to diesel vehicles. However, there is a catenary-equipped trolley by-pass lane at the west end of the building



LEGEND

OVERHEAD CATENARY STRUCTURE

BUS RETURNS FROM SERVICE TO PARKING

BUS MOVES THROUGH FUEL LANE TO PARKING

BUS EXITS TO SERVICE

DEPOT:	Southern	Location:	19th Street and Johnson Street
BUS ASSIGNMENT:	40-ft 186	60-ft 21	Special notes: This facility is equipped with 25 55-kW Proterra chargers

SUMMARY:	Bus depot consists of a single building that houses maintenance bays, fueling lanes, and indoor bus parking. On the site there are paved areas to the south and east for both outdoor bus parking and site circulation. The site is bounded by streets to the north, east, and west and a private business to the south. There is a public park across the street to the east and the rest of the surrounding neighborhood is a mix of housing and commercial.

DEPOT DAILY SERVICE CYCLE
Bus operators drop the farebox vault at the entrance to the site then park buses in parking bays in the building. Later shifters move the buses through fueling/servicing/cleaning and park the buses back in parking bays. Interior cleaning happens at the fuel island.

DEPOT FUELING FACILITY			
Location on site:	Fueling lane in the center of the building		
# Fueling lanes	2	Dispensers/lane	2
Overhead structure type & lighting	Open web joists. There are lights, conduit, and open flame heaters at ceiling level		
In-ground tank location	Next to building at southeast corner		
Location of farebox vault	At entrance to site at southeast corner, off W Moyamensing Avenue		
Location of interior cleaning	At fuel island		

SITE CIRCULATION	
Bus Entrance	Buses enter off W Moyamensing Avenue, at southeast corner of the site
Bus Exit	Buses exit onto W Moyamensing Avenue, at southeast corner of the site
Non-bus Entrance	Same as bus
Non-bus Exit	Same as bus

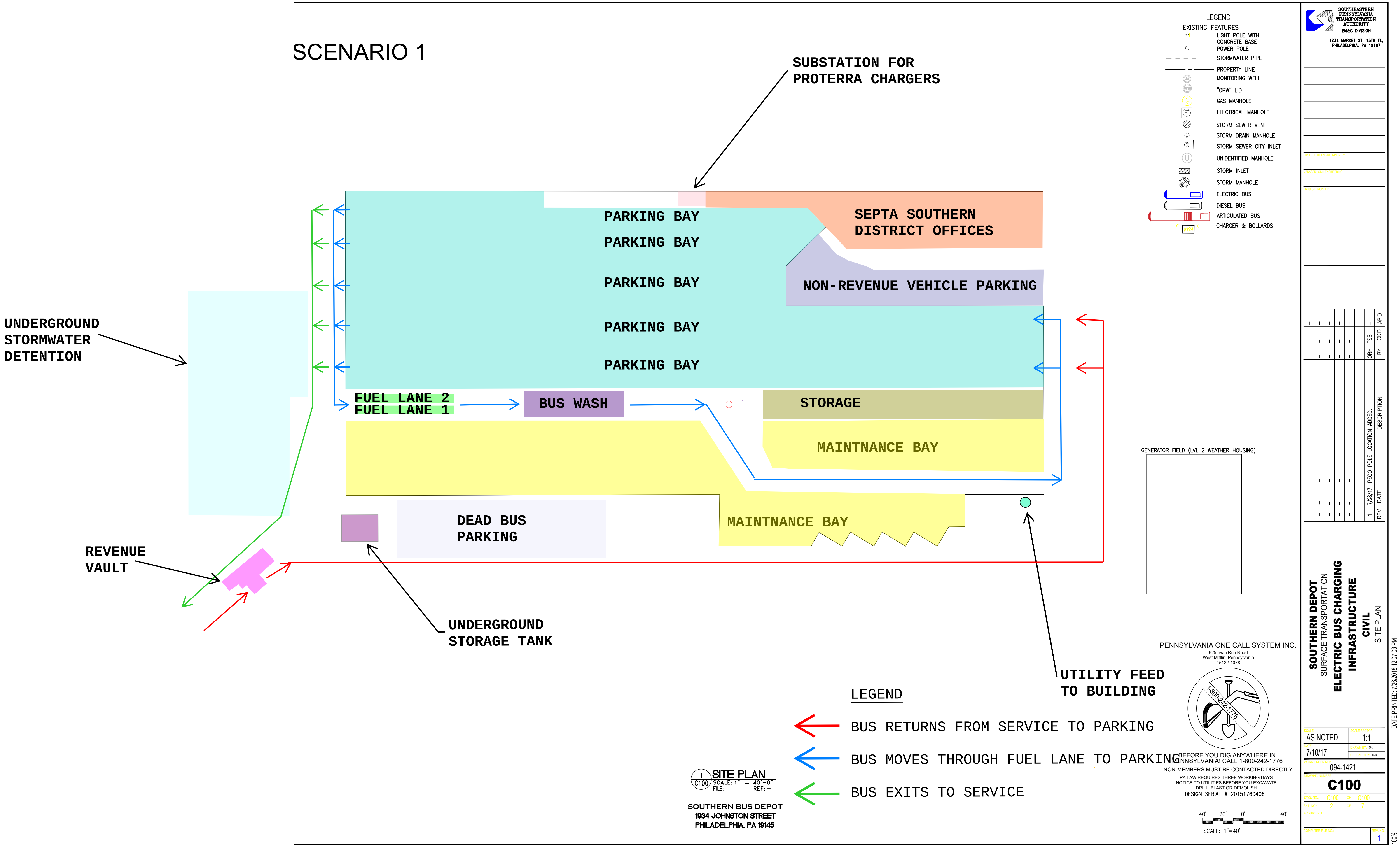
Circulation path for fueling buses Parking – fueling - parking	Buses leave parking bays heading south, the turn left and left to enter fueling lanes headed north. They exit the fueling lane at north end of building and turn left then left to enter parking bays heading south
Circulation path exiting buses	Buses exit parking bays heading south, and turn left and exit the site onto W Moyamensing Avenue

INTERIOR BUS PARKING AREA	
Overhead Structure	Some bays have open web joists, others have concrete beams
Emission sources w/in 18 inches of ceiling?	Lights, conduit, and open flame heaters at ceiling level

OTHER:

- Utility feed to building at northeast corner. Feed is at 13.2 kV, with 480 V transformers on SEPTA property.
- Paved area at south side of site is used for active bus parking
- Paved area on east side of site is used for dead bus parking now (Proterra buses)
- There is underground storm water detention under paved area at southwest corner of the site
- The facility is equipped with 25 55 kW Proterra chargers, mounted along wall in three bus parking bays on west side of the building. There is a “temporary” 2 MW substation for these chargers inside building in middle of western wall

SCENARIO 1



SUBSTATION FOR PROTERRA CHARGERS
PARKING BAY
PARKING BAY
PARKING BAY
PARKING BAY
PARKING BAY
SEPTA SOUTHERN DISTRICT OFFICES
NON-REVENUE VEHICLE PARKING
UNDERGROUND STORMWATER DETENTION
FUEL LANE 2
FUEL LANE 1
BUS WASH
STORAGE
MAINTNANCE BAY
MAINTNANCE BAY
DEAD BUS PARKING
REVENUE VAULT
UNDERGROUND STORAGE TANK
UTILITY FEED TO BUILDING
GENERATOR FIELD (LVL 2 WEATHER HOUSING)
LEGEND
BUS RETURNS FROM SERVICE TO PARKING
BUS MOVES THROUGH FUEL LANE TO PARKING
BUS EXITS TO SERVICE
LEGEND
EXISTING FEATURES
LIGHT POLE WITH CONCRETE BASE
POWER POLE
STORMWATER PIPE
PROPERTY LINE
MONITORING WELL
"OPW" LID
GAS MANHOLE
ELECTRICAL MANHOLE
STORM SEWER VENT
STORM DRAIN MANHOLE
STORM SEWER CITY INLET
UNIDENTIFIED MANHOLE
STORM INLET
STORM MANHOLE
ELECTRIC BUS
DIESEL BUS
ARTICULATED BUS
CHARGER & BOLLARDS
1 SITE PLAN
C100 SCALE: 1" = 40'-0"
SOUTHERN BUS DEPOT
1934 JOHNSTON STREET
PHILADELPHIA, PA 19145
PENNSYLVANIA ONE CALL SYSTEM INC.
925 Irwin Run Road
West Mifflin, Pennsylvania
15122-1078
BEFORE YOU DIG ANYWHERE IN PENNSYLVANIA! CALL 1-800-242-1776
NON-MEMBERS MUST BE CONTACTED DIRECTLY
PA LAW REQUIRES THREE WORKING DAYS NOTICE TO UTILITIES BEFORE YOU EXCAVATE DRILL, BLAST OR DEMOLISH
DESIGN SERIAL # 20151760406
SCALE: 1"=40'
SOUTHEASTERN PENNSYLVANIA TRANSPORTATION AUTHORITY
EM&C DIVISION
1234 MARKET ST, 13TH FL. PHILADELPHIA, PA 19107
REV 1 7/28/17 PECO POLE LOCATION ADDED. ORH TSB
SOUTHERN DEPOT
SURFACE TRANSPORTATION
ELECTRIC BUS CHARGING INFRASTRUCTURE
CIVIL
SITE PLAN
AS NOTED
1:1
7/10/17
094-1421
C100
DATE PRINTED: 7/26/2018 12:07:03 PM

DEPOT:	Callowhill	Location:	350 N 58th Street
BUS ASSIGNMENT:	40-ft 177	60-ft 0	Special notes: Urban location with no outdoor space. 1.9 miles from Victory Depot This depot services steel wheel PCC trolley cars as well as diesel and diesel hybrid buses.

SUMMARY:	Bus depot occupies a full city block, with a single building covering virtually the entire site from sidewalk to sidewalk. The site is bounded by city streets on all four sides, with row houses across the street on three sides, and a park on the fourth. The only paved outdoor space are small aprons at bus entrance/exits onto N 58th Street and N 59th Street. There is no interior bus circulation within the building. Circulation from parking tracks for fueling/servicing happens on the surrounding streets. The northern one third of the building is dedicated to steel wheel PCC trolley cars, and these bays are equipped with tracks and overhead catenary system. The remainder of the building houses and services diesel and diesel hybrid buses

DEPOT DAILY SERVICE CYCLE
Bus operators returning from service drop the farebox at revenue vault on W 58th Street, then park buses in the building parking bays. Later, shifters move the bus through fueling, interior cleaning (at fuel island), bus wash, and back to parking tracks

DEPOT FUELING FACILITY			
Location on site:	First bay in building on south side (next to Vine St)		
# Fueling lanes	2	Dispensers/lane	2
Overhead structure type & lighting	Concrete beams creating pockets. Lights, conduit, and open flame heaters at ceiling level.		
In-ground tank location	Under sidewalk on Vine Street		
Location of farebox vault	Middle of building on 58th Street		
Location of interior cleaning	In fuel lane		

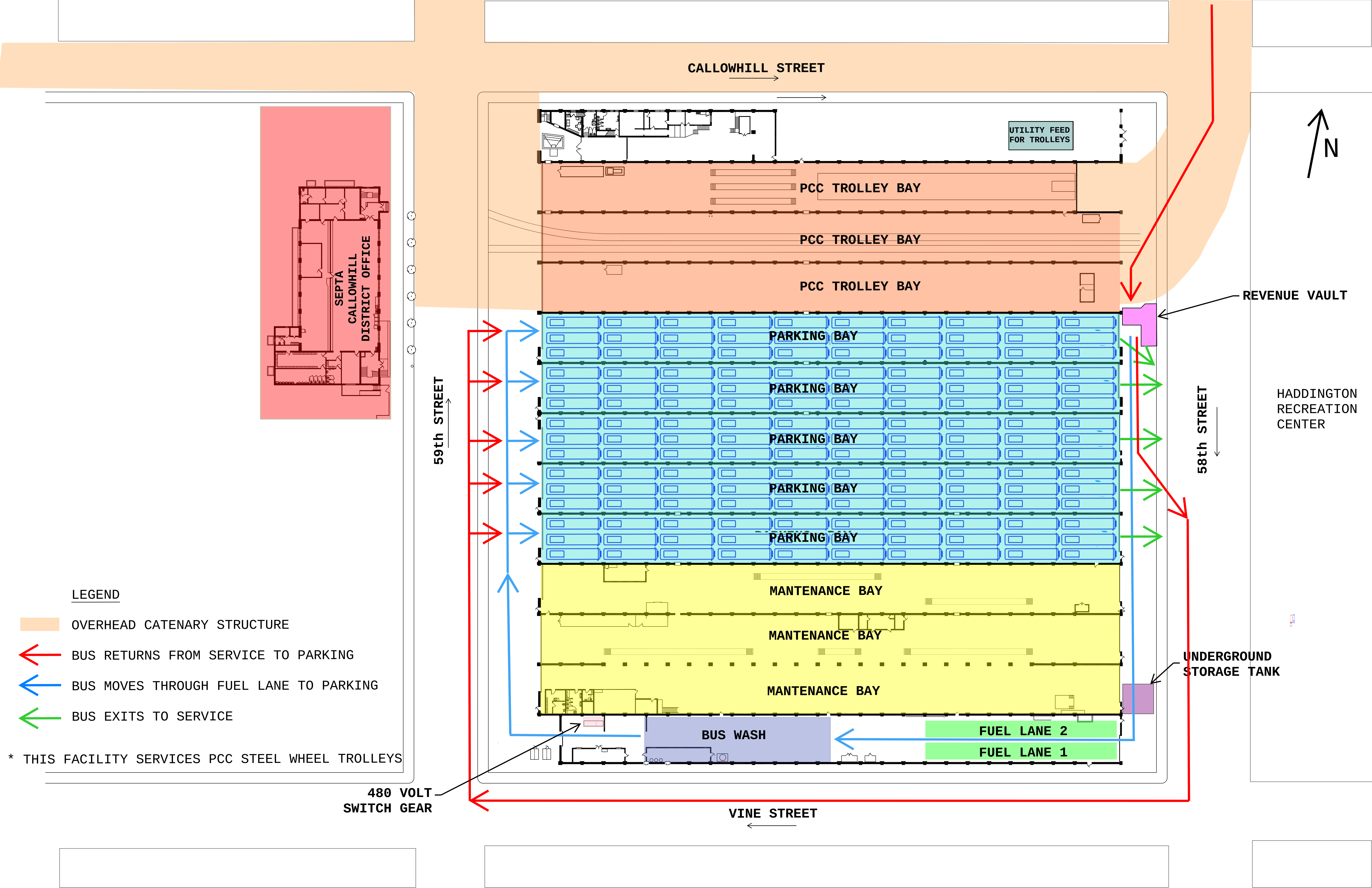
SITE CIRCULATION	
Bus Entrance	From 59th Street
Bus Exit	To 58th Street

Non-bus Entrance	N/A
Non-bus Exit	N/A
Circulation path for fueling buses Parking – fueling - parking	Bus operators returning from service drop the farebox at revenue vault on W 58th Street, then continue down 58th, turn right onto Vine St, then right onto 59th Street and right into bus parking bays heading east. Shifters exit onto 58th Street and turn right, then right onto Vine Street, right onto 59th Street, and right into fuel lane. From fuel lane, right onto 58th Street, right onto Vine Street, right onto 59th Street and right into parking bays
Circulation path exiting buses	From parking bays to 58th street, right or left

INTERIOR BUS PARKING AREA	
Overhead Structure	Concrete beams creating pockets.
Emission sources w/in 18 inches of ceiling? Y/N	Lights, conduit, and open flame heaters at ceiling level.

OTHER:

- One third or building dedicated to steel wheeled PCC trolley cars, and equipped with in-ground rails and overhead catenary power
- Utility feed for trolleys at northeast corner of the building
- Utility feed for building at southwest corner of building. Feed is at 13.2 kV, with 480 V transformers on SEPTA property.
- No exterior paved area on site



CALLOWHILL STREET
UTILITY FEED FOR TROLLEYS
N
PCC TROLLEY BAY
PCC TROLLEY BAY
PCC TROLLEY BAY
REVENUE VAULT
SEPTA CALLOWHILL DISTRICT OFFICE
PARKING BAY
PARKING BAY
PARKING BAY
PARKING BAY
PARKING BAY
59th STREET
58th STREET
HADDINGTON RECREATION CENTER
MANTENANCE BAY
MANTENANCE BAY
MANTENANCE BAY
UNDERGROUND STORAGE TANK
BUS WASH
FUEL LANE 2
FUEL LANE 1
480 VOLT SWITCH GEAR
VINE STREET
LEGEND
OVERHEAD CATENARY STRUCTURE
BUS RETURNS FROM SERVICE TO PARKING
BUS MOVES THROUGH FUEL LANE TO PARKING
BUS EXITS TO SERVICE
* THIS FACILITY SERVICES PCC STEEL WHEEL TROLLEYS

SEPTA SITE VISIT SUMMARY 7/12 – 7/13, 2022

DEPOT:	Frontier	Location:	1525 Alan Wood Road
BUS ASSIGNMENT:	40-ft 105	60-ft 0	Special notes: High priority for FCEB due to assigned suburban routes with high daily energy demand

SUMMARY:	Bus depot site is bounded on one side by Alan Wood Road and bound on the west and south sides by auto dealer parking lots. There is a stream to the north of the site. The depot includes a fuel/wash building, a maintenance building, and significant paved areas for exterior bus parking. Buses are primarily parked in angled spaces rather than on linear tracks.

DEPOT DAILY SERVICE CYCLE
Bus operators drop farebox at revenue vault at North end of parking area then park buses. Later shifters move buses to fuel/wash building for fueling and interior and exterior cleaning and then back to parking area.

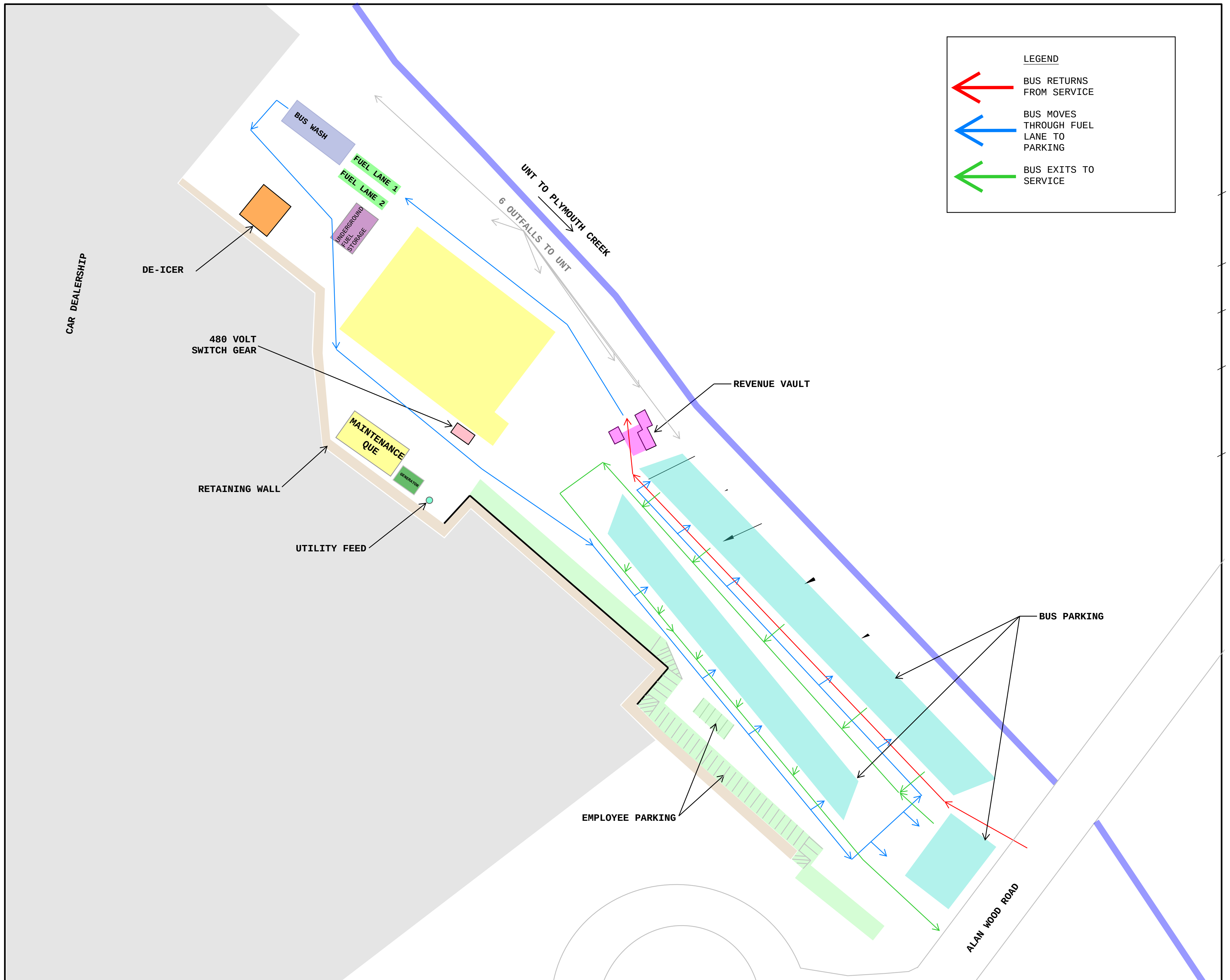
DEPOT FUELING FACILITY			
Location on site:	Separate building at north end of site		
# Fueling lanes	2	Dispensers/lane	1
Overhead structure type & lighting	Open web joists. Lights and conduit at ceiling level. No open flame heaters		
In-ground tank location	To south of fuel building		
Location of farebox vault	At north end of bus parking area, in front of maintenance building		
Location of interior cleaning	At fuel island		

SITE CIRCULATION	
Bus Entrance	Off Alan Wood Road
Bus Exit	To Alan Wood Road
Non-bus Entrance	Same as bus
Non-bus Exit	Same as bus
Circulation path for fueling buses Parking – fueling - parking	From parking area to right side of maintenance building and into fuel building. From fuel building turn left to go to left side of maintenance building to parking area
Circulation path exiting buses	From parking area onto Alan Wood Road

INTERIOR BUS PARKING AREA	
Overhead Structure	N/A all exterior parking
Emission sources w/in 18 inches of ceiling? Y/N	N/A all exterior parking

OTHER:

- Utility service at south edge of property approximately even with south end of maintenance building. Feed is at 13.2 kV. 480 V transformers and switchgear at southwest corner of maintenance building
- Employee parking along south edge of property in bus parking area.
- There are 6 stormwater outfalls along the north side of the property, draining to an unnamed tributary to Plymouth Creek.



1 FRONTIER DISTRICT:
SCALE: 1/32" = 1'-0"

SOUTHEASTERN PENNSYLVANIA TRANSPORTATION AUTHORITY
EM&C DIVISION
1234 MARKET ST, 13TH FL, PHILADELPHIA, PA 19107

MANAGER - ARCH/ENGINEERING, BRIDGES AND BUILDINGS

PROJECT MANAGER

REV	DATE	DESCRIPTION	BY	CK'D	APD

FRONTIER DISTRICT
1525 ALAN WOOD RD, CONSHOHOCKEN, PA, 19428
BEB CHARGER INFRASTRUCTURE

POWER ENGINEERING
SCENARIO 3: INDUCTIVE CHARGING LAYOUT A

SCALE: 1/64" = 1' 0"	SCALE FACTOR: ###
DATE: 8/3/2020	DRAWN BY:
	CHECKED BY:

WORK ORDER NO.:

DRAWING NUMBER

DWG. NO.: OF

SHT. NO.: OF

COMPUTER FILE NO.: ################### REV. NO.: #

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APPENDIX B

FACILITY CONSIDERATIONS

TABLE OF CONTENTS

FACILITY CONSIDERATIONS FOR HYDROGEN FUELED VEHICLES

PRELUDE

The Southeastern Pennsylvania Transit Authority (SEPTA) plans to transition from the current diesel fueled busses to a fleet of zero-emission busses (ZEBs) by the year 2040. A number of these ZEBs will be fuel cell electric busses (FCEBs), which will require facility retrofits in order to accommodate hydrogen regulatory and zoning requirements.

Within the scope of this project, WSP is to develop conceptual design of hydrogen fueling facilities at each SEPTA operating location that will meet the daily fueling requirements for all assigned busses. This document outlines the considerations for hydrogen fueled vehicles, as well as the properties and characteristics of hydrogen, which will be incorporated into the design.

FACILITY CONSIDERATIONS FOR HYDROGEN FUELED VEHICLES

ABBREVIATIONS

AHJ	Authority Having Jurisdiction
Atm	Atmosphere
BTU	British Thermal Unit
CFR	Code of Federal Regulations
CNG	Compressed Natural Gas
Cu	Cubic
Ft	Feet
FCEB	Fuel Cell Electric Bus
GH2	Gaseous Hydrogen
H2 (H_2)	Hydrogen / Molecular Hydrogen
HFCV	Hydrogen Fuel Cell Vehicle
ICC	International Code Congress
In	Inch
kg	Kilogram
LFL	Lower Flammable Limit
LH2	Liquid Hydrogen
m	Meter
mm	Millimeter
NFPA	National Fire Protection Association
PSIG	Pounds per Square Inch, Gauge
SCF	Standard Cubic Feet
UFL	Upper Flammable Limit
ZEB	Zero Emission Bus

SUMMARY

Hydrogen fuel-cell vehicles (HFCV) are in essence electric vehicles that use hydrogen stored on the vehicle to operate a fuel cell in the same manner liquid fuels are stored in more conventional vehicles. However, hydrogen is approximately 14 times lighter than air, so even though it is highly flammable, escaped hydrogen dissipates rapidly.

Building codes and standards have evolved to address the use of lighter than air fuels, and specialized designers use the array of codes, standards, and industry practices, to create best practices. Regardless of published codes and standards, provisions for use of hydrogen fueled vehicles should be closely coordinated with the local authorities having jurisdiction.

A wealth of knowledge and experience related to the safe use and handling of hydrogen exists as a result of an extensive history in a wide variety of industrial and aerospace settings. As with any other energy form or fuel, hydrogen can be used safely when proper procedures and engineering techniques are followed.

The key items to be addressed for retrofit of an existing maintenance facility for use with hydrogen fueled vehicles include:

1. Indoor storage and use areas and storage buildings for hydrogen shall be provided with mechanical exhaust ventilation or engineered fixed natural ventilation that is approved by the AHJ. Proper ventilation can reduce the likelihood of a flammable mixture of hydrogen forming in an enclosure following a release or leak.
2. In vehicle repair rooms, booths, or spaces in major repair facilities where hydrogen vehicles are repaired, the area within 18 in. of the ceiling shall be electrically designated a Class I, Division 2, Group B hazardous (i.e., classified) location, except where a continuous mechanical ventilation system is provided and operating at a rate of not less than 1 scf/min/ft^2 of floor area over the area of storage or use.
3. Major repair garages that repair vehicles powered by hydrogen shall have automatic fire suppression sprinklers throughout the entire building.
4. Rooms, booths or spaces in major repair garages where hydrogen fuel cell vehicles are repaired are to be separated by noncombustible walls and ceilings with a 1-hour rating and with self-closing doors.
5. Major repair garages shall be provided with a listed hydrogen detection system to detect the presence of hydrogen gas where major repairs are performed on hydrogen fueled vehicles. Gas detection systems shall fail-safe and have

addressable detectors. Upon detection of hydrogen, the system shall actuate audio-visual alarms, activate mechanical ventilation systems, and deactivate any non-compatible heating and electrical systems.

6. Heating systems with open flames or surface temperatures greater than 750°F shall be removed from areas where major repairs are performed on hydrogen fueled vehicles.

7. Standby power shall be provided for any hydrogen safety systems such as mechanical ventilation and gas detection systems.

FACILITY CONSIDERATIONS FOR HYDROGEN FUELED VEHICLES

INTRODUCTION

Hydrogen fuel-cell vehicles (HFCV) are in essence an electric vehicle that uses an electrochemical fuel cell to generate electricity onboard in place of externally charged batteries to supply the power. Hydrogen is stored onboard the vehicle to operate the fuel cell in the same manner liquid fuels are stored in more conventional vehicles with internal combustion engines.

However, hydrogen behaves differently from gasoline or diesel, but if applied correctly, it is safer than gasoline which we use routinely. Hydrogen is approximately 14 times lighter than air, so even though it is highly flammable, escaped hydrogen dissipates rapidly.

Building codes and standards have evolved to address the use of lighter than air fuels, and many of the recommended practices for use of hydrogen are similar to the practices for use of compressed natural gas (CNG) fuels, which is used widely in over 175,000 vehicles in the United States.. In some cases, provisions put in place to accommodate CNG fuels also serve the requirements for hydrogen fuel.

The design of facilities for hydrogen fueled vehicles is regulated, and guided, by codes and standards that include:

1. NFPA 2, Hydrogen Technologies Code.
2. NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages.
3. NFPA 55: Compressed Gases and Cryogenic Fluids Code
4. NFPA 70, National Electrical Code.
5. NFPA 88A, Standard for Parking Structures (NFPA 88A refers to NFPA 2)
6. ICC, International Mechanical Code.
7. ICC, International Fire Code.
8. OSHA Regulations 29 CFR 1910, Subpart H (https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.103)

Codes and standards relating to installation, operation, and maintenance of facilities for vehicles fueled with lighter than air fuels such as hydrogen and compressed natural gas (CNG) are still evolving.. Facilities for maintenance of vehicles using hydrogen fuels are designed to code requirements, as well as reference guidelines and current industry practice.

Code provisions define the minimum acceptable standards to which facilities are allowed to be built in a given area. Code requirements define a degree of safety, performance, and quality that has been generally accepted by building officials and refined over time. Industry standards expand on code requirements by defining additional technical recommendations that are adopted by the specialty technical organization which published such standards. Standards are generally adopted through a consensus process, and as such are subject to input from parties with special interests, and publishing delays. Industry practice represents how facilities are actually designed and constructed at a given time. Industry practice and standards often adopt provisions before those provisions appear in codes due to the delay in updating the codes.

Codes may adopt industry standards by reference, but if not adopted by a code in force in a local jurisdiction, the provisions of that standard, which might be more current, may be considered optional.

Designers interpret the array of codes, standards, and industry practices, to make a judgment of what might be considered best practice. These judgments consider available guidance to provide a level of safety, but such judgments may involve subjective selection between two or more alternatives, each of which meets the prescribed guidance. Future codes may or may not adopt industry practice and standards that are in place today, and owners and designers should consider what represents best practice at such time as a facility is designed, constructed or modified.

FACILITY CONSIDERATIONS FOR HYDROGEN FUELED VEHICLES

HYDROGEN (H_2) PROPERTIES AND HAZARDS

Hydrogen Characteristics

Gaseous hydrogen consists of 100% hydrogen, which at atmospheric conditions is much lighter than air, and quickly rises when not otherwise contained. In contrast, diesel and gasoline vapors are heavier than air, and settle to the ground. Facilities for maintenance of hydrogen fueled vehicles need to be constructed to limit sources of ignition for flammable gas that may be accidentally released, and to evacuate any such gas that is released. Facilities in which a combination of diesel, unleaded and lighter than air gas fueled vehicles may be maintained need to restrict ignition sources where flammable fumes may accumulate, both near the floor, and near the ceiling.

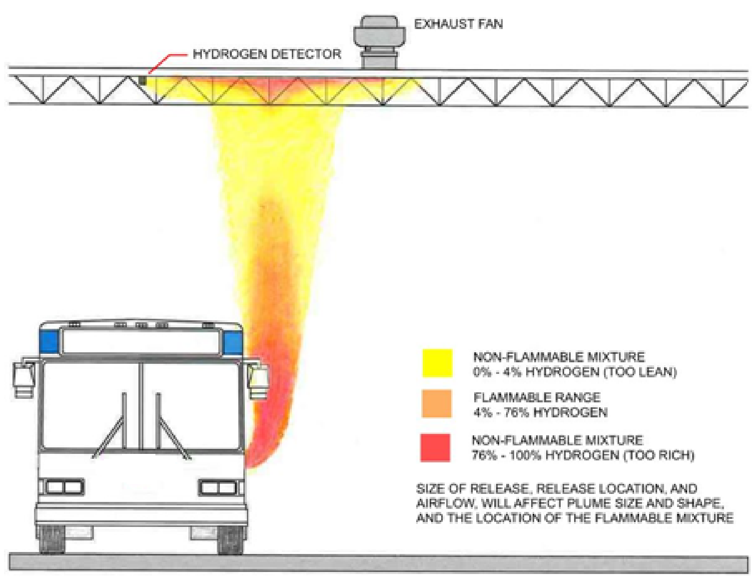
For fuel vapors to catch fire, the fuel must exist in certain proportions as a combustible gas and air mixture, along with an ignition source with sufficient energy to ignite the mixture. The minimum concentration of a particular combustible gas in air required to support its combustion is defined as the lower flammable limit (LFL), for that gas. Below this level, the mixture is too "lean" to burn. The maximum concentration of a gas that will burn in air is defined as the upper flammable limit (UFL). Above this level, the mixture is too "rich" to burn. The range between the LFL and UFL is the flammable range for that gas. Hydrogen is flammable in a wide range of 4% to 76% mixture with air. Properties of H_2 are outlined in greater detail, and compared with conventional liquid fuels, in Table 1.

Since hydrogen is lighter than air at ambient conditions, hydrogen that may be released will behave as a buoyant gas and tend to rise naturally. A high-pressure release may initially act as a neutrally buoyant gas, but as it dissipates the gas will become buoyant. The rising gas plume mixes with surrounding air and the concentration of the gas will decrease. The gas plume will either: (1) Continue to rise in a space until it reaches a fixed barrier such as a ceiling where the gas will spread across the fixed barrier, and may separate from the ambient air to increase the gas concentration; or (2) Become neutrally buoyant as it mixes with air, and the gas will then tend to move around with the ambient air currents.

Compressed hydrogen stored in containers on vehicles is too rich to ignite. In the event of a leak from a hydrogen fueled vehicle, the gas leaving the vehicle will not ignite. As the gas escaping from the vehicle rises and mixes with air, the concentration of gas in air will drop until the mixture is within the flammable range. As the gas plume continues to rise and mix with air the concentration of gas in air will continue to drop below the LFL at which point the mixture will be too lean to burn. When the rising plume reaches the ceiling, the plume will collect and gas that is lighter than air will separate from air. The concentration of gas may then increase to a point within the flammable range, or more at which point the gas concentration would again be too rich to burn. As the plume collects, the mixture will spread out across the ceiling.

In the event of a release of flammable gas, before the gas dissipates to a non-flammable concentration, there will necessarily be a flammable mixture of gas somewhere between the point of the leak which is too rich to burn, and the point at which the gas-air mixture becomes too lean to burn. If gas detectors are installed and detect gas at a nominated percentage of the LFL, a flammable mixture must exist somewhere between the source of the leak and the detector. This concept is illustrated in Exhibit 3.1. The location of the flammable mixture would generally be above the location of the leak as the gas rises, but the actual location of the flammable mixture would be unknown. The location and size of the flammable mixture is dependent on many factors, including, but not limited to, the pressure and volume of the release, the location of the release, and surrounding ambient airflow.

Exhibit 3.1: Flammable Gas Plume Behavior



Properties of Hydrogen

Hydrogen is lighter than air and has a higher ignition temperature than gasoline or diesel fuel, so it naturally rises and dissipates in open air, and it is more difficult to ignite than gasoline or diesel vapors.

Hydrogen is a colorless, odorless gas. Unlike compressed natural gas, which is odorized with mercaptan as a safety precaution so leaking CNG can be detected by smell the same as natural gas used for comfort heating, hydrogen used in HFCV is not odorized. Because of the buoyancy of hydrogen, 2.5 times the odorant would be required to effectively odorize hydrogen than to odorize natural gas, and the odorants used to odorize CNG contaminate the catalysts used in hydrogen fuel cells,. Therefore, hydrogen is not odorized and requires hydrogen gas sensors to detect and alert operators to the presence of the odorless, colorless, gas.

Additional specific properties of hydrogen gas are presented in Exhibit 3.2 and compared with gasoline, diesel, and CNG.

Typical fuel storage on a New Flyer fuel cell bus is per bus is 37.5kg (82.67 lbs) of gaseous hydrogen with an expected range of 350 miles. The volume and density of a gas changes with temperature and pressure but mass stays the same. For this reason, quantities of hydrogen are usually given in mass (kg or lb). At standard temperature and pressure of 20˚C (68˚F), and 1atm., Hydrogen gas has a density of 0.0899 kg/m3 or 0.0056 lb/ft^3. 1 kg or 2.198 lbs of H_2 gas at standard conditions = 11.1235 m^3 or 392.5 ft^3 (SCF).

The amount of GH2 needed to fuel a bus for a day assuming substantially empty storage tanks is 37.5kg (82.67 lbs) of GH2 per bus per day. For a fleet of 250 busses 9,375 kg (20,668.34 lbs) of GH2 would be required per day, which at STP is 83,426 m^3 (2,953,125 ft^3).

Exhibit 3.2: Properties of Select Liquid and Gaseous Fuels

Property	Gasoline	Diesel number 2	CNG	Hydrogen
Physical state	Liquid	Liquid	Compressed Gas	Compressed Gas or Liquid
Relative Vapor density (Air = 1)	3.5	5	0.56	0.07
Boiling range (°F @ 1 atm)	80 to 420	320 to 720	-259	-423
Energy content (lower heating value) Btu/lb, Btu/gal	112,114 – 116,090	128,488	20,160	51,585
Energy content (higher heating value) Btu/lb, Btu/gal	120,388 – 124,340	138,490	22,453	61,013
Autoignition temperature (oF)	495	600	1004	1,050 to 1,080
Flashpoint (oF)	-45	165	-306	N/A
Octane number range (R+M) 2	84 to 93	n/a	120	130+
Flammability limits (volume % in air)	L = 1.2 H = 7.1	L = 0.7 H = 5.0	L = 5 H = 15	L = 4 H = 76
Gasoline/diesel gallon equivalent	97% - 100%	1 gallon of diesel has 111% of the energy of one gallon of gasoline.	123.57 cu ft. of CNG has 100% of the energy of one gallon of gasoline. 6.38 pounds or 139.30 cu ft. of CNG has 100% of the energy content of one gallon of diesel.	1 kg or 2.198 lbs. of H_2 has 100% of the energy of one gallon of gasoline. 0.9 kg or 1.973 lbs. of H2 has 100% of the energy of one gallon of gasoline.

FACILITY DESIGN REQUIREMENTS FOR HYDROGEN FUELED VEHICLES

General Requirements

Exhibit 3.3: Maximum Allowable Quantity of Hydrogen per Control Area (Quantity Thresholds Requiring Special Provisions)

(From NFPA 2, Table 6.4.1.1.1)

	Unsprinklered Areas		Sprinklered Areas	
Material	**No Gas Cabinet, Gas Room, or Exhausted Enclosure**	**Gas Cabinet, Gas Room, or Exhausted Enclosure**	**No Gas Cabinet, Gas Room, or Exhausted Enclosure**	**Gas Cabinet, Gas Room, or Exhausted Enclosure**
GH_2	1000 ft^3 (28 m^3)	2000 ft^3 (56 m^3)	2000 ft^3 (56 m^3)	4000 ft^3 (112 m^3)

Note: The maximum quantity indicated is the aggregate quantity of materials in storage and use combined.
**A gas cabinet or exhausted enclosure is required (see also 6.4.1.1.2).*

Standby and Emergency Power

Where the following systems are required for the storage or use of hydrogen that exceed the quantity thresholds requiring special provisions, and where emergency power is not provided, such systems shall be connected to a standby power system in accordance with NFPA 70:

1. Mechanical ventilation
2. Treatment systems
3. Temperature controls
4. Alarms
5. Detection systems
6. Other electrically operated systems

Emergency power systems shall meet the requirements for a Level 2 system in accordance with NFPA 110 or NFPA 111.

Ventilation

Indoor storage and use areas and storage buildings for hydrogen shall be provided with mechanical exhaust ventilation or engineered fixed natural ventilation that is approved by the AHJ. Continuous ventilation shall be provided at a rate of not less than 1 scf/min/ft^2 of floor area over the area of storage or use unless an alternative design is approved by the AHJ.

For gases that are lighter than air, the ventilation system shall include exhaust taken from a point within 12 in. of the ceiling and not recirculated.

Ventilation discharge systems conveying hydrogen mixtures shall terminate at a point outdoors not less than:

1. 30 ft from property lines,
2. 10 ft from operable openings into buildings,
3. 6 ft from exterior walls and roofs,
4. 30 ft from combustible walls and operable openings into buildings that are in the direction of the exhaust discharge,
5. 10 ft above adjoining grade,
6. As far as practical from adjacent equipment that is not listed for operation in a classified environment (assume a minimum separation of 10 ft. to adjacent electrical equipment. Note that the minimum 10 ft. separation between exhaust outlets and building openings or intakes required by mechanical codes does not account for potentially flammable vapors and nearby ignition sources.)

Outdoor Aboveground Storage.

The distance from outdoor bulk hydrogen systems to various exposures is dependent on the operating pressure of the system, piping size, and type of exposure. Compressed hydrogen for use on HFCV will range from 5,000 to 10,000 psi. Exposures are categorized in three groups as follows:

Exposures Group 1

1. Lot lines
2. Air intakes (HVAC, compressors, other)
3. Operable openings in buildings and structures
4. Ignition sources such as open flames and welding

Exposures Group 2

1. Exposed persons other than those servicing the system
2. Parked cars

Exposures Group 3

1. Buildings of non-combustible non-fire-rated construction
2. Buildings of combustible construction
3. Flammable gas storage systems above or below ground
4. Hazardous materials storage systems above or below ground
5. Heavy timber, coal, or other slow-burning combustible solids
6. Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, or combustible waste and vegetation other than that found in maintained landscaped areas
7. Unopenable openings in building and structures
8. Encroachment by overhead utilities (horizontal distance from the vertical plane Below the nearest overhead electrical wire of building service)
9. Piping containing other hazardous materials
10. Flammable gas metering and regulating stations such as natural gas or propane.

Due to the storage pressure for HFCV, the minimum distance from a gaseous hydrogen system located outdoors to specified exposures shall be in accordance with NFPA 2, Table 7.3.2.3.1.1(A)(c), excerpts of which are included below for reference.

Exhibit 3.4: Minimum Distance (D) from Outdoor Bulk Hydrogen Compressed Gas Systems to Exposures by Maximum Pipe Size with Pressures >3000 to ≤15,000 psig
(From NFPA 2, Table 7.3.2.3.1.1(A)(c))

Pressure	>3000 to ≤7500 psig >20,684 to ≤51,711 kPa			>7500 to ≤15,000 psig >51,711 to ≤103,421 kPa		
	Exposures			Exposures		
Internal Pipe Diameter (ID)	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
ID (in.)	Ft	Ft	Ft	Ft	Ft	Ft
0.2	5	5	7	7	7	9
0.3	14	11	10	18	14	14
0.4	24	16	14	31	22	19
0.5	33	22	18	43	30	24
0.6	42	28	22	55	38	29
0.7	51	33	26	67	46	34
0.8	60	39	29	79	53	39
0.9	70	45	33	91	61	44
1.0	79	50	37	103	69	49
1.1	88	56	41	115	76	54
1.2	97	62	45	127	84	59
1.3	106	67	49	139	92	64
1.4	116	73	52	152	100	69
1.5	125	79	56	163	107	74
1.6	134	84	60	175	115	79
1.7	143	90	64	188	123	84
1.8	152	96	68	199	131	89
1.9	162	102	72	212	139	94
2.0	171	107	75	224	146	99

Note: Linear interpolation of internal pipe diameters and distances between table entries is allowed.

Except for distances to air intakes, the distances to Group 1 and 2 exposures may be reduced by one-half and shall not apply to Group 3 exposures where fire barrier walls are located between the system and the exposure.

Maintenance and Repair Facilities

The National Fire Protection Association (NFPA) classifies vehicle repair garages in two categories to differentiate between risk associated with the type of repairs being performed on vehicles. Repair Garages are classified as Major or Minor Repair Garages and these classifications are used in most of the NFPA codes applicable to hydrogen fuel cell vehicles, including NFPA 2, NFPA 30A, and NFPA 70. Major and Minor Repair Garages are characterized as follows:

> Major Repair Garage. A building or portions of a building for major repairs, such as work on the hydrogen storage system, the fuel system, repairs that require defueling of the hydrogen fuel cell vehicle, and maintenance or repairs that require open flame cutting or welding.
>
> Minor Repair Garage. A building or portions of a building used for lubrication, inspection, and minor automotive maintenance work, such as engine tune-ups, replacement of parts, fluid changes (e.g., brake fluid, air conditioning refrigerants), brake system repairs, tire rotation, and similar routine maintenance work.

Major repair garages that only repair vehicles powered by hydrogen shall comply with NFPA 2. Major repair garages that repair vehicles powered by hydrogen as well as other fuels including gasoline, diesel and CNG shall comply with NFPA 2 and NFPA 30A.

NFPA 2 allows for repairs that would be required to be performed in a major repair garage to be performed in a minor repair garage if the vehicle is defueled in accordance to less than 400 scf and the fuel supply container is sealed. A typical HFCB might have a fuel capacity of 37.5kg or 11,775 SCF.

Sprinklers

In buildings with a major repair garage, automatic fire suppression sprinklers shall be provided throughout the entire building.

Construction

NFPA 2 allows repairs to HFCV in a Major Repair Garage in rooms or booths constructed to prevent migration of fugitive hydrogen to adjacent areas. Walls, doors, and ceilings that intersect or enclose a repair area are to be constructed of noncombustible or limited combustible materials or assemblies and securely and rigidly mounted.

Interior surfaces of the repair area shall be smooth, non-porous and constructed to facilitate ventilation.

Repair rooms shall be separated from surrounding areas of the building by assemblies that have a fire resistance rating of one hour.

Repair booths shall be separated from other operations by a minimum distance of 3 ft., or by a partition, wall, or floor/ceiling assembly having a fire resistance rating of not less than one hour. The clear space of not less than 3 ft shall be maintained on all sides and above a repair booth unless a 1-hour rated partition is provided and the integrity of the booth is maintained. Multiple connected repair booths may be considered as a single operation without separation.

Supplemental Construction Recommendations:

1. Install automatic doors to close off untreated areas such as parts rooms and machine shops. These should close upon gas detection."
2. Install self-closing man doors to close off untreated areas from the garage.
3. Install bulkheads in stairways and hallways that could lead to a gas plume migrating into untreated areas. This approach can be evaluated against or combined with HVAC system pressure balancing to keep a plume out of these areas."
4. Remove, pressurize or ventilate plenum area above ceilings to prevent intrusion and collection of flammable gas.
5. Seal and fire stop wall penetrations in walls separating repair garage areas from adjacent occupancies.

<u>Defueling Equipment</u>

Hydrogen fuel shall be discharged from storage containers before maintenance or repair is performed on the fuel storage system, or when welding or open flame activities occur within 18 in. of the vehicle fuel container. Major repair garages require defueling equipment to empty vehicle fuel supply containers.

<u>Gas Detection System</u>

Major repair garages shall be provided with an approved hydrogen detection system to detect the presence of hydrogen gas where vehicle hydrogen fuel storage systems are serviced or where defueling is performed indoors.

The detection system shall activate an alarm or other safety systems and measures such as ventilation systems, or selective system shutdown and record the gas concentration at each sensor location. Detectors should be configured to have multiple alarm levels such as a low-level alarm that activates an audible signal and increases ventilation and a high-level alarm that initiates a system shutdown and notifies first responders. Alarm levels should be set not more than 25% of the hydrogen lower flammable limit.

The hydrogen detection system shall provide coverage of the motor vehicle service area, and have sensors in the following locations:

1. At inlets to exhaust systems
2. At high points in service bays
3. At the inlets to mechanical ventilation systems

Catalytic technology is required to detect hydrogen leaks. Infrared (IR) technology will not detect GH2. Catalytic sensors should be calibrated four times per year and sensors should be replaced every three to four years.

Point detectors are recommended for Hydrogen. Open path detectors use IR, so they can't be used for Hydrogen. Point detectors should be installed at high points throughout the facility (approximately 15' from walls and 30' from the next detector (NTS)). For hydrogen, "detectors are required at the inlet to exhaust air systems and mech ventilation inlets where GH2 vehicles are serviced or defueled (NFPA 2 Section 18.3.3.4)".

Gas detection systems shall fail-safe. A failure of a system component shall place the system into response mode. Subject to approval by the AHJ, a trouble signal to a monitored location in response to a component failure with a brief time delay before activating the response mode, may be acceptable.

A unique identification tag should be assigned to each detector and label so the status of each detector can be electronically monitored. Each detector should be labeled so it is visible from the floor. Calibration tubing should be installed at floor level, or an automatic calibration system should be installed to facilitate and reduce the cost and operational interruption of calibration.

Gas detection circuits shall be monitored for integrity as required in NFPA 72.

Gas detection controllers for hydrogen shall be listed and labelled to UL 2017 or UL 864 and detectors shall be labeled to UL 2075.

Visible status lights should be provided inside the garage and outside above overhead doors to alert workers when hydrogen is detected, as well as when the system is operational.

Manual gas detection activation buttons are recommended at personnel exit doors.

Activation of the hydrogen detection system shall:

1. Initiate distinct audible and visual alarm signals in the repair garage
    1. It is recommended that an alarm also be activated in a location that

2. is continuously occupied and monitored such as a dispatch center, security office, or remote service center.

3. Consideration should be given to activating a general alarm throughout connected building areas in the event of a high-level alarm.

2. Deactivate all heating systems located in the repair garage except for classified heaters that are listed and labeled for Class I, Division 1, and remote sources of heating, such as forced hot air, hot water, or steam where the furnace, boiler, heat pump, etc. is located in a separate area that does not draw air from the repair area]

3. Activate the mechanical ventilation system.

Activation of the hydrogen detection system may also initiate actions such as:

1. Disconnect power to electrical equipment with open-bus power supplies, such as cranes and hoists, particularly those located above vehicle service bays.

2. Disconnect power to welding receptacles or similar fixed equipment.

3. Disconnect power to other electrical equipment located above vehicle service bays and not listed for use in a classified environment.

4. Open select motorized doors to allow for supplemental ventilation or make-up air.

Exhibit 3.5: Suggested Gas Detection System Response.

	Initiating Event				
Gas Detection System Response	**25% LFL Low Level**	**50% LFL High Level**	**Manual Activation**	**System Trouble Non-Critical**	**System Failure**
Gas Detection Strobes (Normal = Green)	Amber	Red	Red	Blue	Red
Gas Detection Horns	X	X	X		X
Shut-down applicable heaters	X	X	X	X	X
Open select outside overhead doors for ventilation Close doors between shop and adjacent areas.	X	X	X		X
Start Emergency Fans	X	X	X		X
Remove Power for Crane and Welding/Sparking	X	X	X		X
Report and Display Fault on FACP		X	X		X
Non-latching: Automatic Reset When Condition Clears	X			X	
Latching: Manual System Reset When Condition Clears		X	X		X

Heating, Ventilating, and Air Conditioning.

Forced air heating, air-conditioning, and ventilating systems serving a garage shall not be interconnected with any such systems serving other occupancies in the building.

Combined ventilation and heating systems shall only recirculate air from areas that are more than 455 mm (18 in.) below the ceiling level.

Open-flame heaters and heating equipment with exposed surface temperatures over 750˚F (400˚C) are prohibited in Major Repair Garages for hydrogen vehicles within 18 in. of the ceiling or in areas subject to ignitable concentrations of gas, including such items as unit heaters and heating and ventilating units with gas fired or electric coils, and most infrared radiant heaters. Some manufacturers offer low intensity radiant heaters with sealed combustion chambers and low surface temperatures, but these units are less effective than standard infrared heaters, and any gas fired may effectively have an open flame if installed incorrectly or as a result of damage and corrosion over time.

A mechanical hydrogen exhaust system with exhaust drawn from within 12 inches of the high point of the ceiling shall be provided for each room, booth, or space for major repair of hydrogen fueled vehicles. Exhaust shall discharge outdoors not less than

5. 30 ft from property lines,
6. 10 ft from operable openings into buildings,
7. 6 ft from exterior walls and roofs,
8. 30 ft from combustible walls and operable openings into buildings that are in the direction of the exhaust discharge,
9. 10 ft above adjoining grade,
10. As far as practical from adjacent equipment that is not listed for operation in a classified environment (assume a minimum separation of 10 ft. to adjacent electrical equipment. Note that the minimum 10 ft. separation between exhaust outlets and building openings or intakes required by mechanical codes does not account for potentially flammable vapors and nearby ignition sources.)

For repair rooms, booths, or spaces where hydrogen vehicles are repaired, the area within 18 in. of the Electrical Classification ceiling shall be designated a Class I, Division 2, Group B hazardous (i.e., classified) location, except where a continuous mechanical ventilation system is provided and operating at a rate of not less than 1 scf/min/ft^2 of floor area over the area of storage or use. A local visual and audible alarm shall activate and repair activities shall cease upon the loss of continuous ventilation.

Note that mechanical codes may allow for intermittent ventilation to avoid classification, but this practice is not recommended due to known presence of flammable mixture in the event of a release (See Section 2.1 and Figure 1). Exhaust air should be discharged vertically upward and away from fresh air intakes and equipment.

The mechanical code specifies a minimum separation of 10 ft between an exhaust outlet and an air intake of building opening to prevent contamination of indoor air, but that distance does not consider potential ignition sources such as combustion air intakes or motor enclosures. Being much lighter than air, hydrogen will tend to rise quickly, but it is best practice to analyze wind patterns and exhaust airflow direction to prevent flammable vapors from coming in contact with ignition sources. It is recommended that exhaust air that may contain hydrogen be discharged at least 10 feet from all parts of any adjacent equipment and be discharged vertically upward (upblast fans).

It is recommended that ventilation air be supplied at floor level to helps dilute leaks and push gas plumes towards ceiling detection and exhaust systems. Maintenance areas should also be designed such that normal air pressure in the area is negative relative to adjacent spaces to inhibit migration of flammable gases.

Heat recovery systems such as plate heat exchangers or run-around coils should be considered for energy conservation. Heat wheels are not acceptable as they include a purge section that can recycle air containing hydrogen mixtures.

Areas adjacent to classified locations where flammable vapors are not likely to be released, such as stock rooms, switchboard rooms, and other similar locations, where mechanically and continuously ventilated at a rate of four or more air changes per hour, designed with positive air pressure, or effectively isolated by walls or partitions, may be designated unclassified.

Electrical Classification

Exhibit 3.6: Extent of Classified Locations for Major Repair Garages with Lighter-than-Air Fuel

(From NFPA 30A & NFPA 70)

	Class I		
Location	**Division[2]**	**Zone[3]**	**Extent of Classified Location**
Repair garage, major (where lighter than-air gaseous fueled[1] vehicles are repaired or stored)	2 Unclassified	2 Unclassified	Within 450 mm (18 in.) of ceiling, except as noted below Within 450 mm (18 in.) of ceiling where ventilation of at least .3 m^3/min/m^2 (1 ft^3/min/ft^2) of floor area, with suction taken from a point within 450 mm (18 in.) of the highest point in the ceiling
Specific areas adjacent to classified locations	Unclassified	Unclassified	Areas adjacent to classified locations where flammable vapors are not likely to be released, such as stock rooms, switchboard rooms, and other similar locations, where mechanically ventilated at a rate of four or more air changes per hour or designed with positive air pressure, or where effectively cut off by walls or partitions

[1]Includes fuels such as hydrogen and natural gas, but not LPG.

[2]For hydrogen (lighter than air) Group B, or natural gas Group D.

[3]For hydrogen (lighter than air) Group IIC or IIB+H2, or natural gas Group IIA.

Parking Garages

NFPA recommends that vehicles powered by gaseous or liquid hydrogen in parking garages be subject to the same requirements applicable to vehicles powered by traditional fuels. NFPA provides no supplemental recommendations for construction of parking garages to be used for storage of hydrogen fueled vehicles.

NFPA determined that the fire hazard presented by vehicles powered by GH2 or LH2 is sufficiently similar to those presented by vehicles fueled by liquid gasoline or diesel fuel that no additional requirements are warranted. The combustible components common to all vehicles can cause a vehicle fire to spread from one parked vehicle to another but the presence of hydrogen fuel is not a major cause of fire spread.

Parking garages to be used for storage of HFCV should be constructed in accordance with the locally adopted building and fire codes.

Vehicle Fueling Facilities

Dispensing equipment shall be provided with hydrogen gas detection, leak detection, and flame detection at the fueling area.

An emergency manual shutdown device shall be provided at the dispensing area and also at a location remote from the dispensing area.

Canopies that are used to shelter dispensing operations shall meet or exceed Type I construction requirements of the adopted building code and be constructed in a manner that prevents the accumulation of hydrogen gas.

With the approval of the AHJ, the classified areas specified above shall be permitted to be reduced or eliminated by positive-pressure ventilation from a source of clean air or inert gas in accordance with methods recognized in NFPA 496.

Fire extinguishers and warning signs are required in the fueling area.

Exhibit 3.7: Electrical Installations

Location	Division or zone	Extent of Classified Area
Outdoor dispenser enclosure — exterior and interior	2	Up to 5 ft (1.5 m) from dispenser
Indoor dispenser enclosure — exterior and interior	2	15 ft (4.6 m) from the point of transfer
Outdoor discharge from relief valves or vents	1	5 ft (1.5 m) from source
Outdoor discharge from relief valves or vents	2	15 ft (4.6 m) from source
Discharge from relief valves within 15 degrees of the line of discharge	1	15 ft (4.6 m) from source

Outdoor Fueling

Exhibit 3.8: Separation Distances for Outdoor Gaseous Hydrogen Dispensing Systems

System Component	Exposure	Required Separation ft	Required Separation m
Dispensing equipment	Nearest important building or line of adjoining property that can be built upon or from any source of ignition	10	3.0
Dispensing equipment	Nearest public street or public sidewalk	10	3.0
Dispensing equipment	Nearest rail of any railroad main track	10	3.0
Point of transfer	Any important building other than buildings of Type I or Type II construction with exterior walls having a fire resistance rating of not less than not less than 2 hours	10	3.0
Point of transfer	Buildings of Type I or II construction with exterior walls having a fire resistance rating of not less than 2 hours or walls constructed of concrete or masonry, or of other material having a fire resistance rating of not less than 2 hours	No limit	No limit
Point of transfer	Storage containers	3	1.0

Indoor Fueling

Rooms within or attached to other buildings shall be constructed of noncombustible or limited-combustible materials except window glazing shall be permitted to be plastic.

1. Interior walls or partitions shall be continuous from floor to ceiling, shall be anchored, and shall have a fire resistance rating of at least 2 hours.
2. At least one wall shall be an exterior wall.
3. Explosion venting shall be provided in exterior walls or roof.
4. Access to the room shall be from outside the primary structure.
5. If access to the room from outside the primary structure is not possible, access from within the primary structure shall be permitted where such access is made through a vapor-sealing, self-closing fire door having the appropriate rating for the location where installed.

Indoor fueling locations shall be provided with mechanical exhaust ventilation at a rate of not less than 1 scf/min/ft2 of floor area.

A ventilation system for a room within or attached to another building shall be separate from any ventilation system for the other building.

A gas detection system shall be provided and equipped to sound a latched alarm and visually indicate when a maximum of one-quarter of the lower flammable limit is reached.

Walls, ceilings, and floors within 15 ft (4.6 m) of the dispenser shall be constructed as fire barriers having a fire resistance rating not less than two hours.

Other Operational Considerations

In and around Philadelphia there are several areas with shared right-of-way with the light rail system. Overhead catenary system (OCS) are considered no more of a hazard with operation of hydrogen buses than other electrical systems that may be nearby. NFPA determined that the fire hazard presented by vehicles powered by GH2 or LH2 is similar to those presented by vehicles fueled by liquid gasoline or diesel fuel in normal operation, and no cases of GH2 igniting due to OCS wires were found in online research. Static OCS does not present an ignition source, and an ignition source only exists as a result of arcing between the contact wire and a pantograph. Such arcing would need to be concurrent with a hydrogen release such as from a pressure relief device (PRD), and PRD releases are rare. Hydrogen is much lighter than air and small releases of hydrogen dissipate quickly. Regardless of published and anecdotal information, provisions for use of hydrogen fueled vehicles should be closely coordinated with the local fire marshal.

OTHER RESOURCES AND CONSIDERATIONS

Clean Air Program: Design Guidelines for Bus Transit Systems Using Hydrogen as an Alternative Fuel

U.S. Department of Transportation, Federal Transit Agency
DOT-FTA-MA-26-7021-98-1
DOT-VNTSC-FTA-98-6
Office of Research, Demonstration, and Innovation
October 1998 Final Report

Hydrogen Technologies Safety Guide

National Renewable Energy Laboratory (NREL)
C. Rivkin, R. Burgess, and W. Buttner
Technical Report
NREL/TP-5400-60948
January 2015

Hydrogen Vehicle and Infrastructure Codes and Standards Citations

National Renewable Energy Laboratory (NREL)
NREL/BR-5400-57943
October 2013

29 CFR 1910.103 (OSHA) Requirements for Hydrogen Systems

The Occupational Safety and Health Administration (OSHA) establishes requirements for hydrogen systems in 29 CFR 1910.103. The tabular distances reflect those values published in the July 1, 2006, edition of the CFR. The criteria established in OSHA's tables of distances are based on the 1969 edition of NFPA 50A. Six subsequent editions of NFPA 50A were adopted before NFPA 50A was integrated into NFPA 55 in 2003. NFPA 55 was revised again in 2005.

Throughout the eight revision cycles of NFPA 50A and then NFPA 55, the tabular distances in the NFPA codes were revised as the technology in the use of hydrogen advanced. However, the tabular distances listed in the OSHA tables remain based on the 1969 data. While the OSHA tables may represent the current Federal statutory requirements, it should be recognized that the OSHA tables cases lack clarity and hazards recognized by the ongoing evolution of the separation tables have not been acknowledged.

As examples of the disparity between the OSHA requirements and current codes, the OSHA Table G.2(a) (Building or structure) refers to buildings by construction types, including wood frame, heavy timber, ordinary, and fire resistive, but current construction codes and NFPA codes on building construction use building types designated as Types I through V, with variations to address the elements of construction. OSHA Table G.2(a) also specifies separation distance from flammable liquids, but excludes combustible liquids, and the OSHA table does not address distances for separation from property lines, public sidewalks.

NFPA 2 includes OSHA Table G.2(a) and Table G.2(b) in Annex G to inform the reader of NFPA 2 of the minimum requirements under 29 CFR and the federal OSHA program. Owners, designers and installers and property owners should understand the limitations of OSHA based on the precedent requirements established with the use of the 1969 edition of NFPA 50A. The use of the recommendations for separation distance included in NFPA 2 is subject to approval on a case by case basis. Traditionally, the authority having jurisdiction (AHJ) has been a building or fire official, but other authorities may have input to the review and approval process.

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APPENDIX C

CONCEPTUAL HYDROGEN FUELING LAYOUTS

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		245
2	60' BUS		62
	TOTAL		307
	TOTAL ASSIGNED BUSES		307

PROJECT NO.	30901231
DRAWN BY	JK
DATE	10/24/2022
SCALE	22x34 1" = 100' 11 X 17 1" = 200'

PROJECT TITLE
SEPTA DEPOT MIDVALE

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
MIDVALE SITE W AERIAL

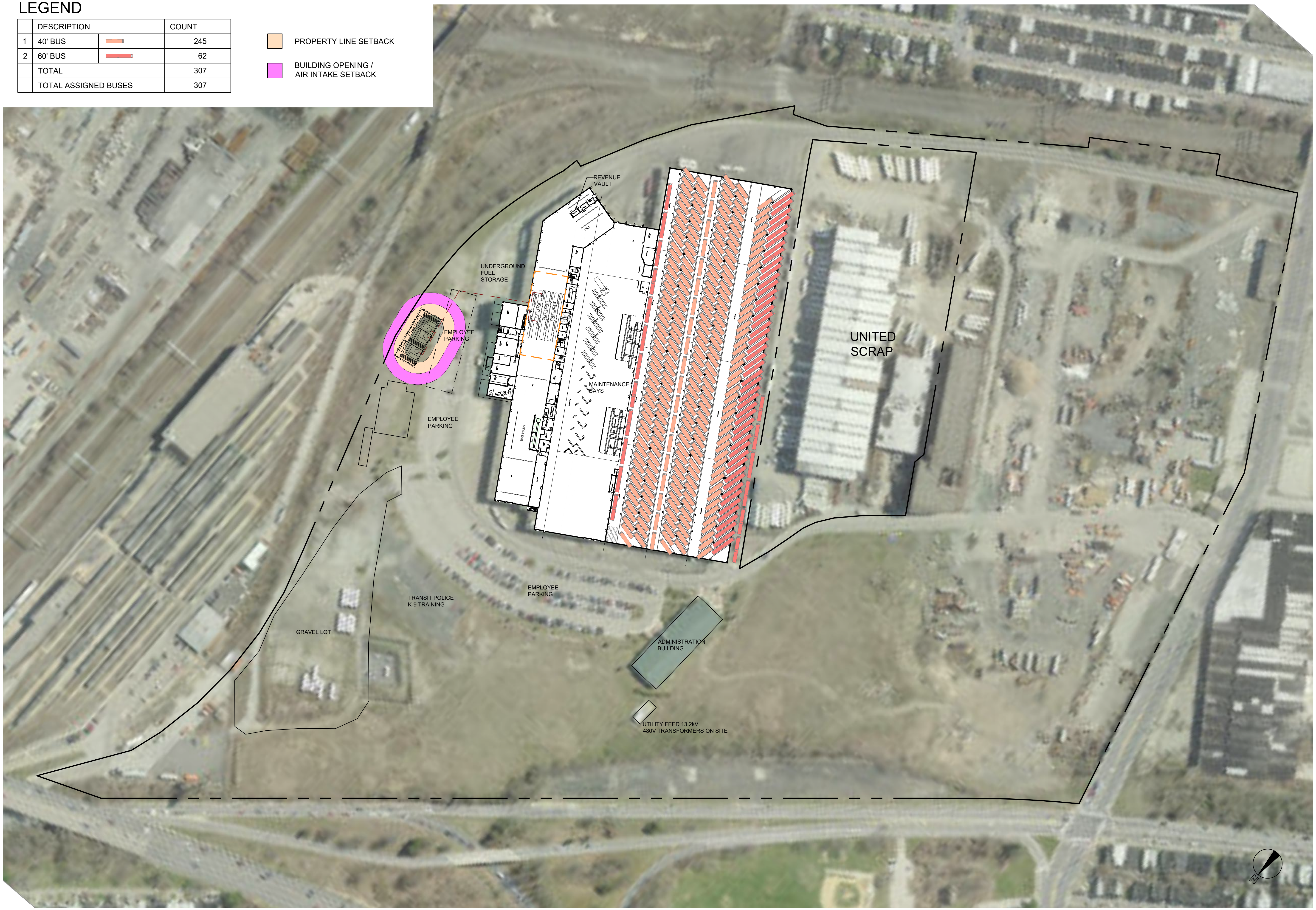
DRAWING NUMBER
EX 01

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		245
2	60' BUS		62
	TOTAL		307
	TOTAL ASSIGNED BUSES		307

PROPERTY LINE SETBACK

BUILDING OPENING / AIR INTAKE SETBACK



PROJECT NO.	30901231
DRAWN BY	JK
DATE	12/06/2022
SCALE	22x34 1" = 100' 11 X 17 1" = 200'

PROJECT TITLE

SEPTA DEPOT MIDVALE

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE

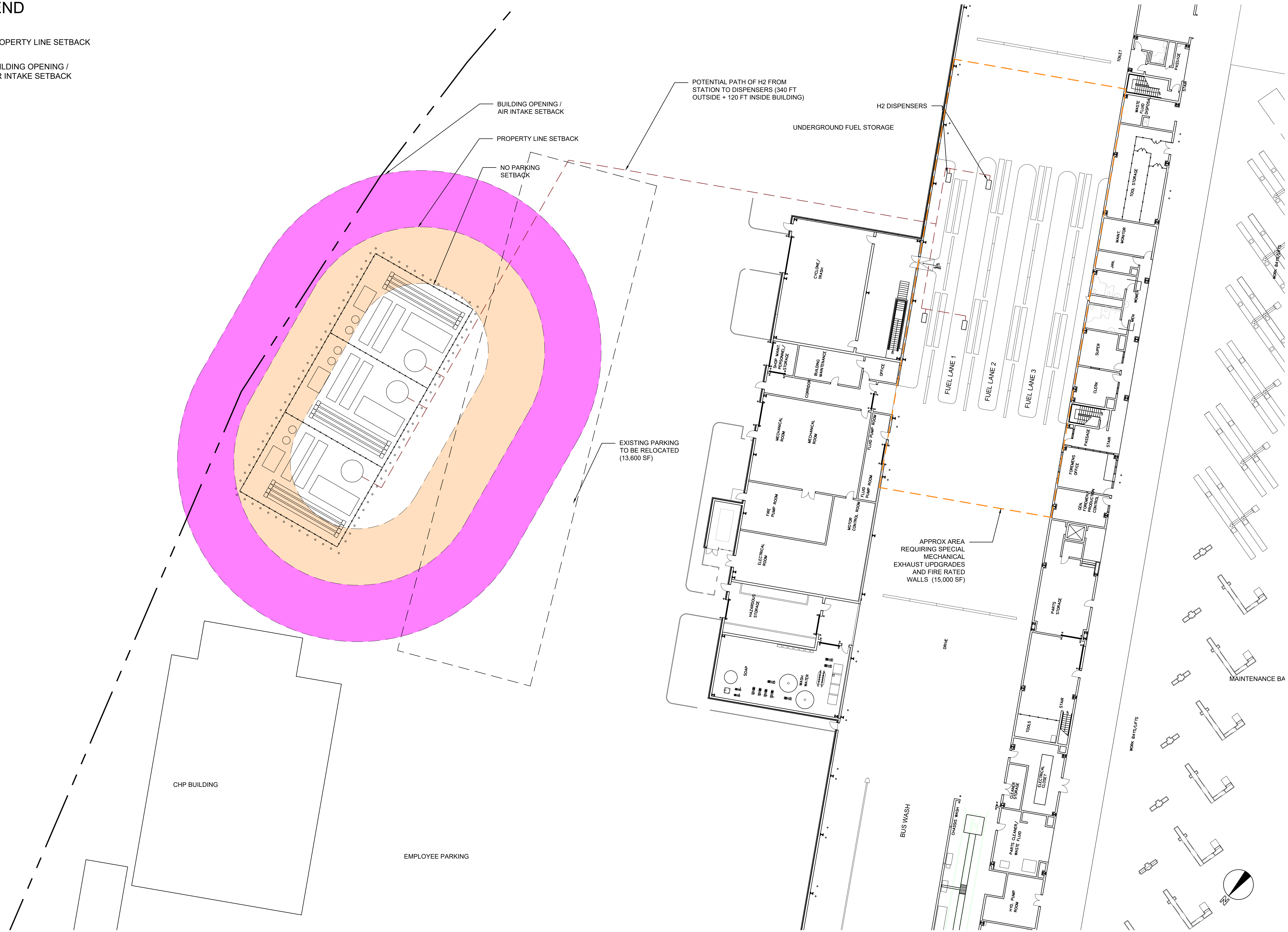
LH2 W/ SETBACKS MIDVALE ONLY

DRAWING NUMBER

M01

LEGEND

- PROPERTY LINE SETBACK
- BUILDING OPENING / AIR INTAKE SETBACK



PROJECT NO.	30901231
DRAWN BY	JK
DATE	12/06/2022
SCALE	22x34 1" = 20' 11 X 17 1" = 40'

PROJECT TITLE

SEPTA DEPOT MIDVALE

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE

LH2 WITH SETBACKS MIDVALE ONLY

DRAWING NUMBER

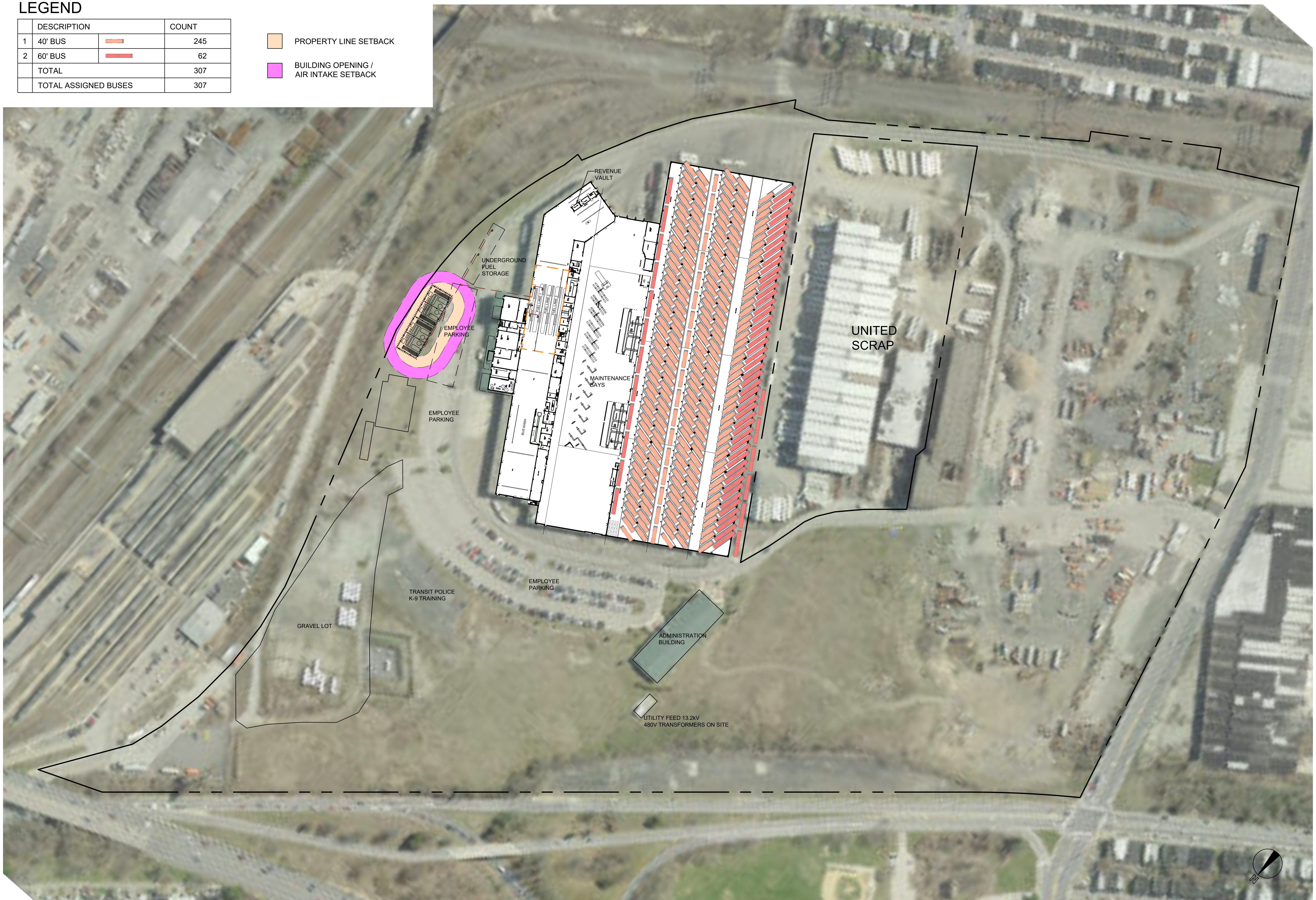
M01_1

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		245
2	60' BUS		62
	TOTAL		307
	TOTAL ASSIGNED BUSES		307

PROPERTY LINE SETBACK

BUILDING OPENING / AIR INTAKE SETBACK



PROJECT NO. 30901231

DRAWN BY JK

DATE 12/06/2022

SCALE 22x34 1" = 100'; 11 X 17 1" = 200'

PROJECT TITLE

SEPTA DEPOT MIDVALE

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE

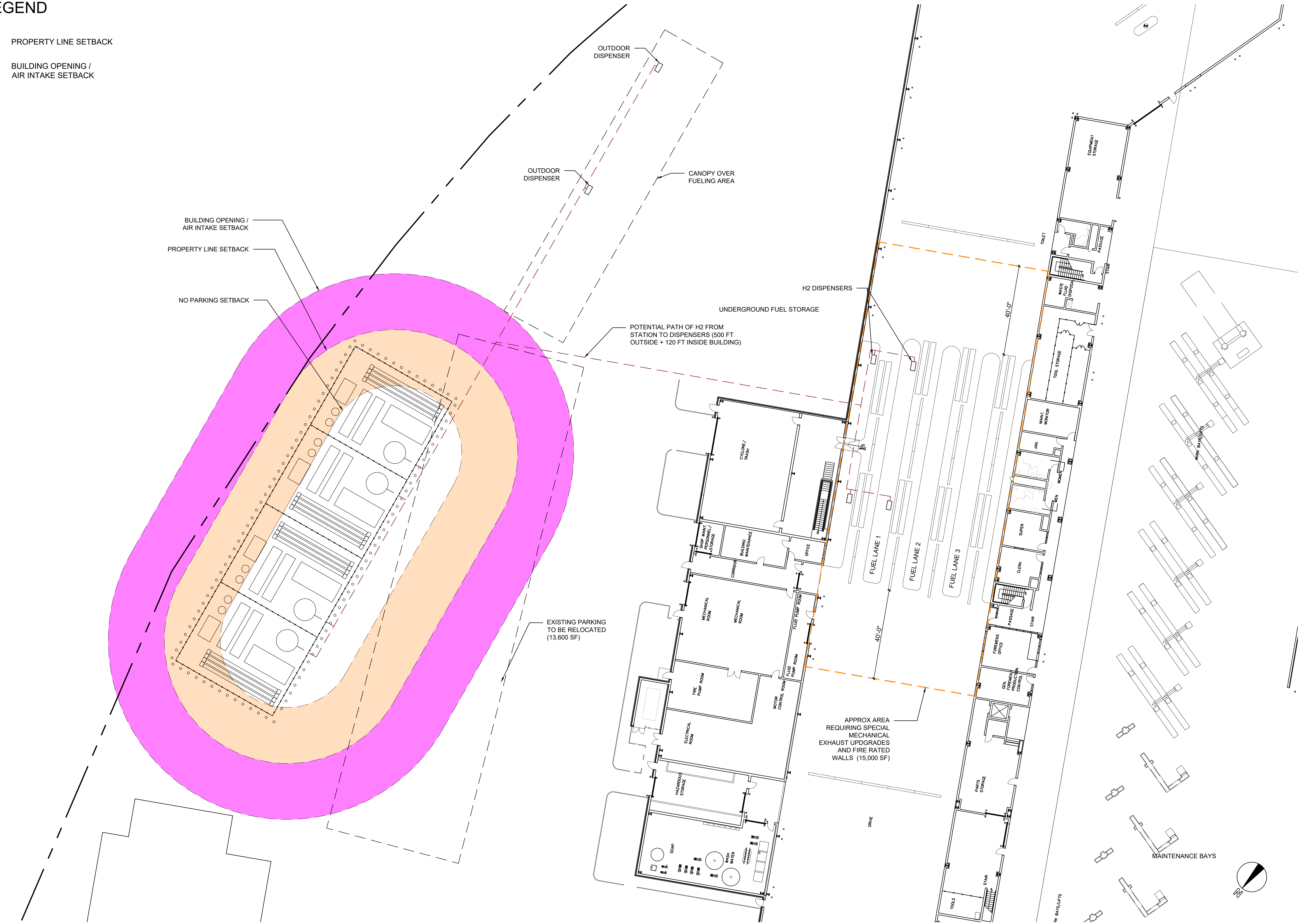
LH2 W/ SETBACKS MIDVALE & ALLEGHENY

DRAWING NUMBER

MA01

LEGEND

- PROPERTY LINE SETBACK
- BUILDING OPENING / AIR INTAKE SETBACK



PROJECT NO.	30901231
DRAWN BY	JK
DATE	12/06/2022
SCALE	22x34 1" = 20' / 11 X 17 1" = 40'

PROJECT TITLE
SEPTA DEPOT MIDVALE

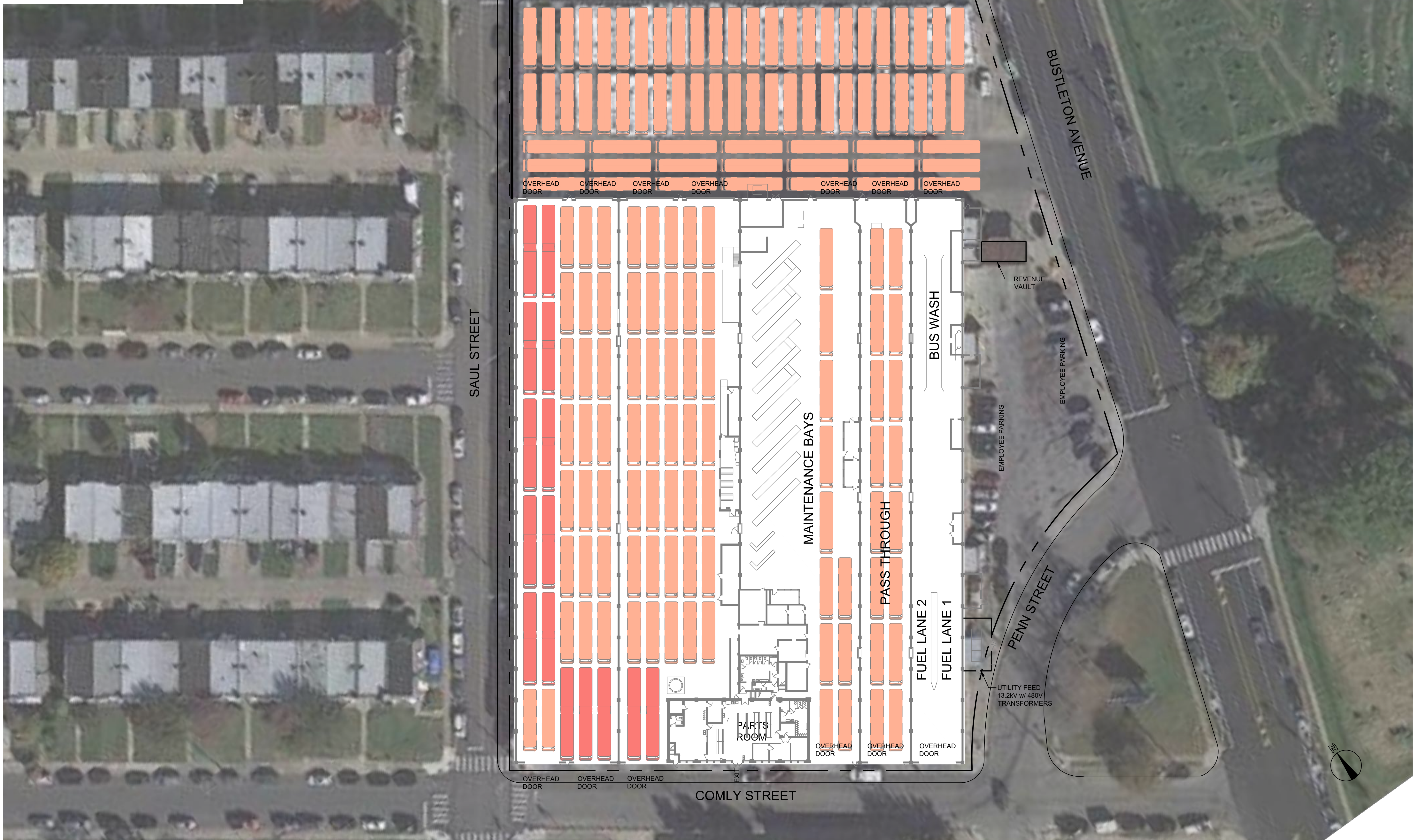
WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 W/ SETBACKS MIDVALE & ALLEGHENY

DRAWING NUMBER
MA01_1

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		154
2	60' BUS		15
	TOTAL		169
	TOTAL ASSIGNED BUSES		169



PROJECT NO.	30901231
DRAWN BY	JK
DATE	9/7/2022
SCALE	22x34 1" = 30' 11 x 17 1" = 60'

PROJECT TITLE
SEPTA DEPOT
COMLY

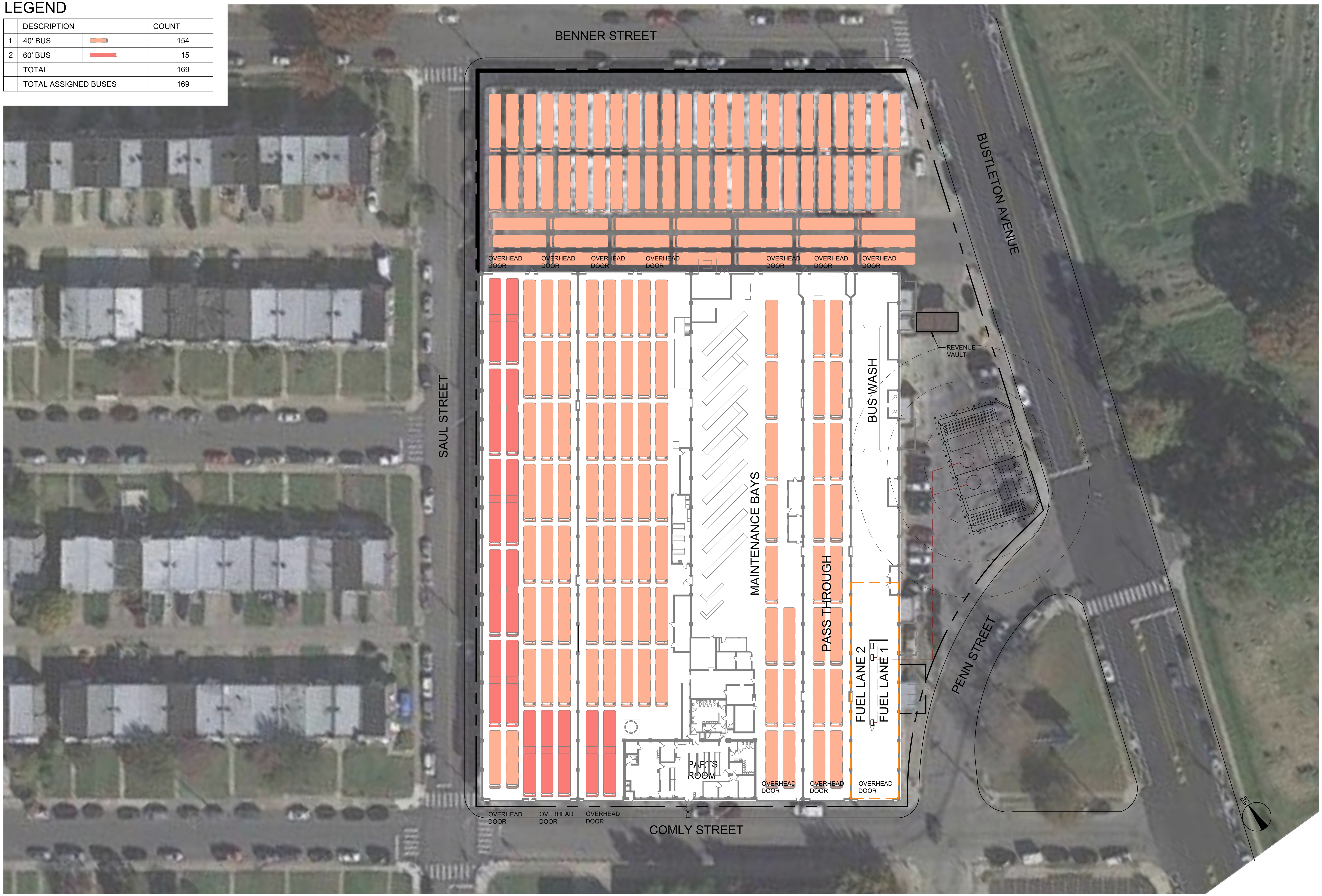
WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
EXISTING W/ AERIAL
COMLY

DRAWING NUMBER
EX 01

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		154
2	60' BUS		15
	TOTAL		169
	TOTAL ASSIGNED BUSES		169



PROJECT NO.	30901231
DRAWN BY	JK
DATE	11/01/2022
SCALE	22x34 1" = 30' 11 X 17 1" = 60'

PROJECT TITLE
SEPTA DEPOT COMLY

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 STATIONS W/ CONTAINMENT WALLS

DRAWING NUMBER
C01

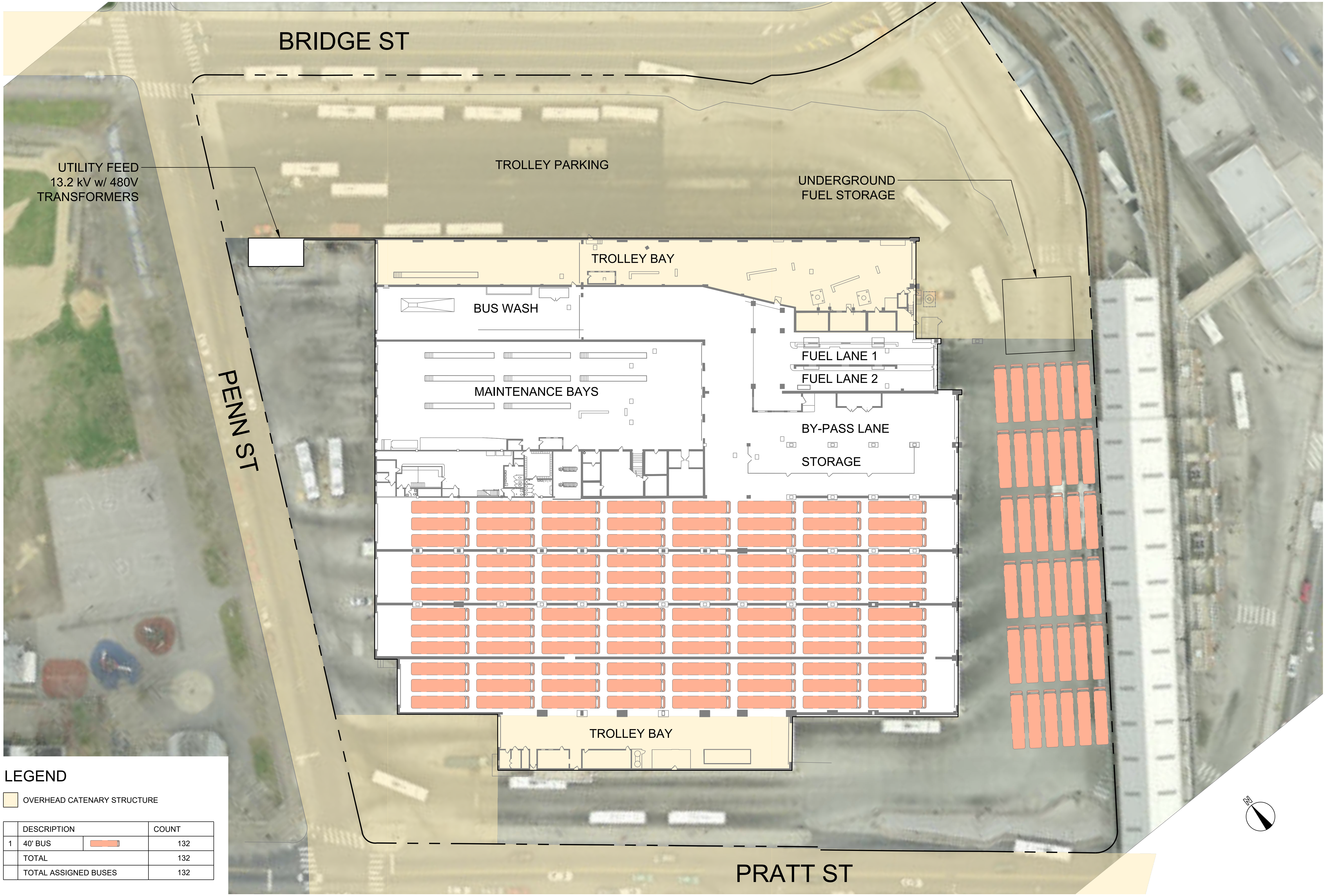
PROJECT NO. 30901231
DRAWN BY JK
DATE 11/01/2022
SCALE 22x34 1" = 20'
11 X 17 1" = 40'

PROJECT TITLE
SEPTA DEPOT COMLY

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 STATIONS W/ CONTAINMENT WALLS

DRAWING NUMBER
C01_1



LEGEND

OVERHEAD CATENARY STRUCTURE

	DESCRIPTION		COUNT
1	40' BUS		132
	TOTAL		132
	TOTAL ASSIGNED BUSES		132

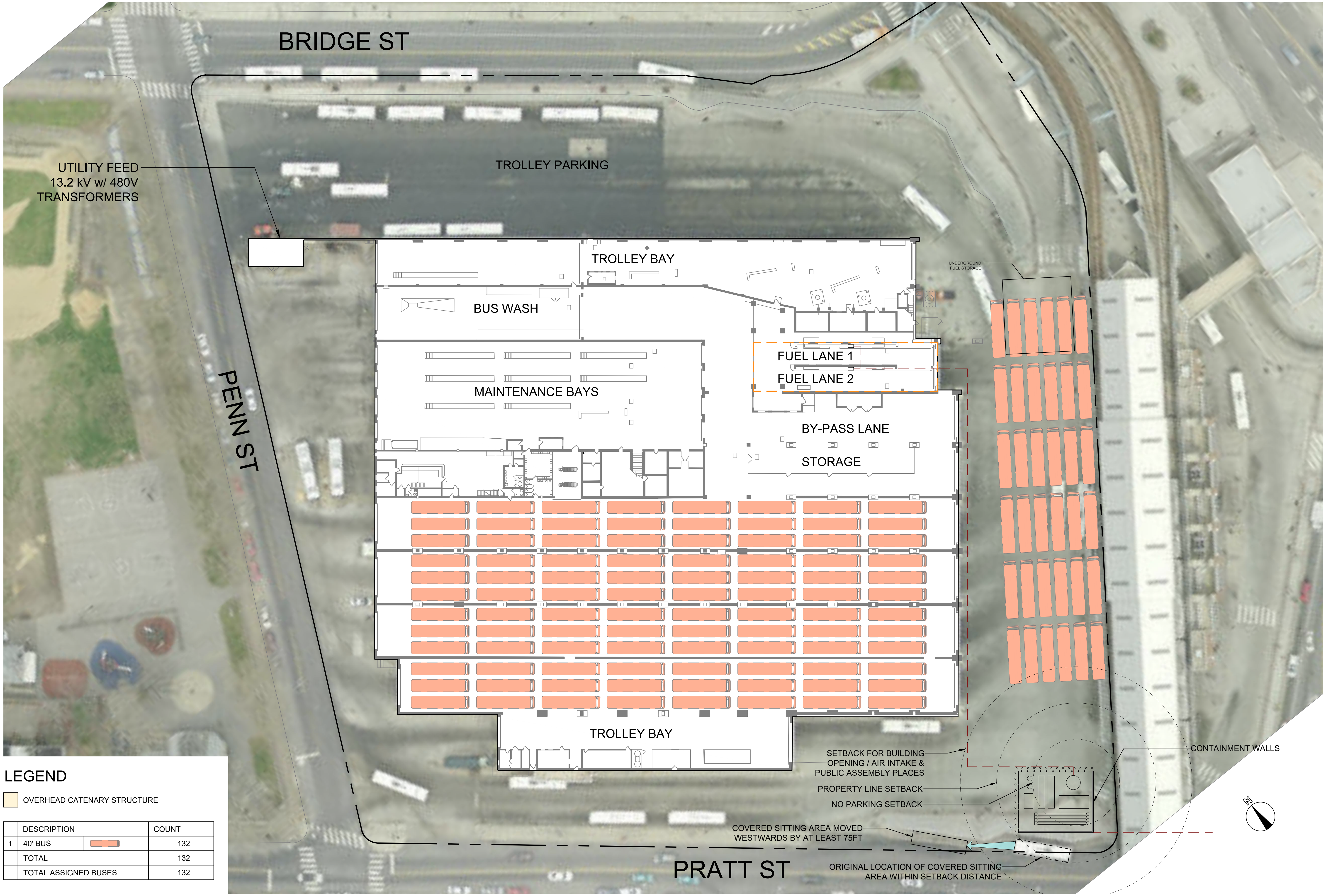
PROJECT NO. 30901231
DRAWN BY JK
DATE 9/7/2022
SCALE 22x34 1" = 40'
11 X 17 1" = 80'

PROJECT TITLE
SEPTA DEPOT
FRANKFORD

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
EXISTING W/ AERIAL
FRANKFORD

DRAWING NUMBER
EX 01



LEGEND

OVERHEAD CATENARY STRUCTURE

	DESCRIPTION		COUNT
1	40' BUS		132
	TOTAL		132
	TOTAL ASSIGNED BUSES		132

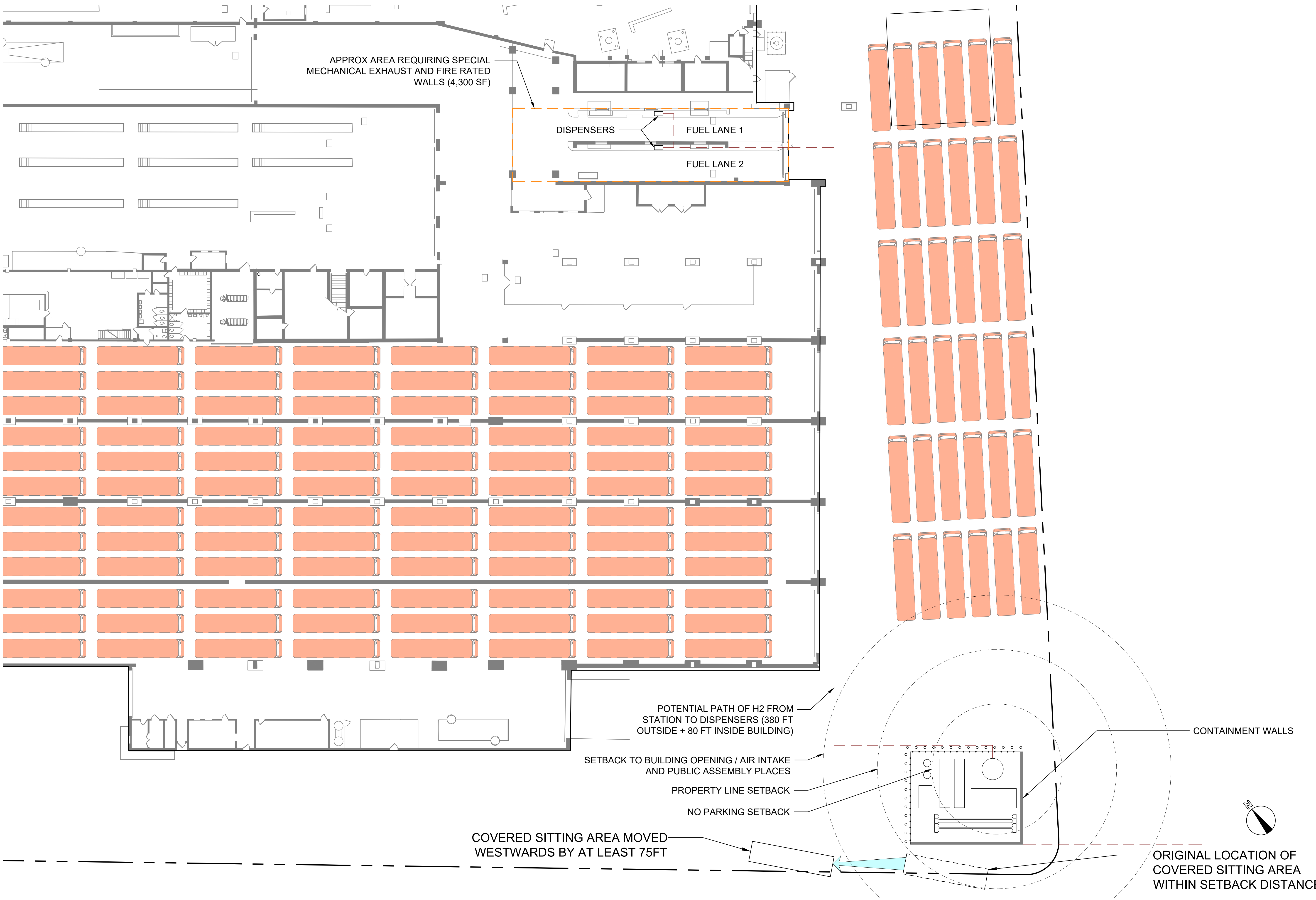
PROJECT NO.	30901231
DRAWN BY	JK
DATE	11/01/2022
SCALE	22x34 1" = 40' 11 X 17 1" = 80'

PROJECT TITLE
SEPTA DEPOT FRANKFORD

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 STATION W/ SETBACKS & CONTAINMENT WALLS

DRAWING NUMBER
FD01



PROJECT NO. 30901231

DRAWN BY JK

DATE 11/01/2022

SCALE 22x34 1" = 20'
11 X 17 1" = 40'

PROJECT TITLE
SEPTA DEPOT FRANKFORD

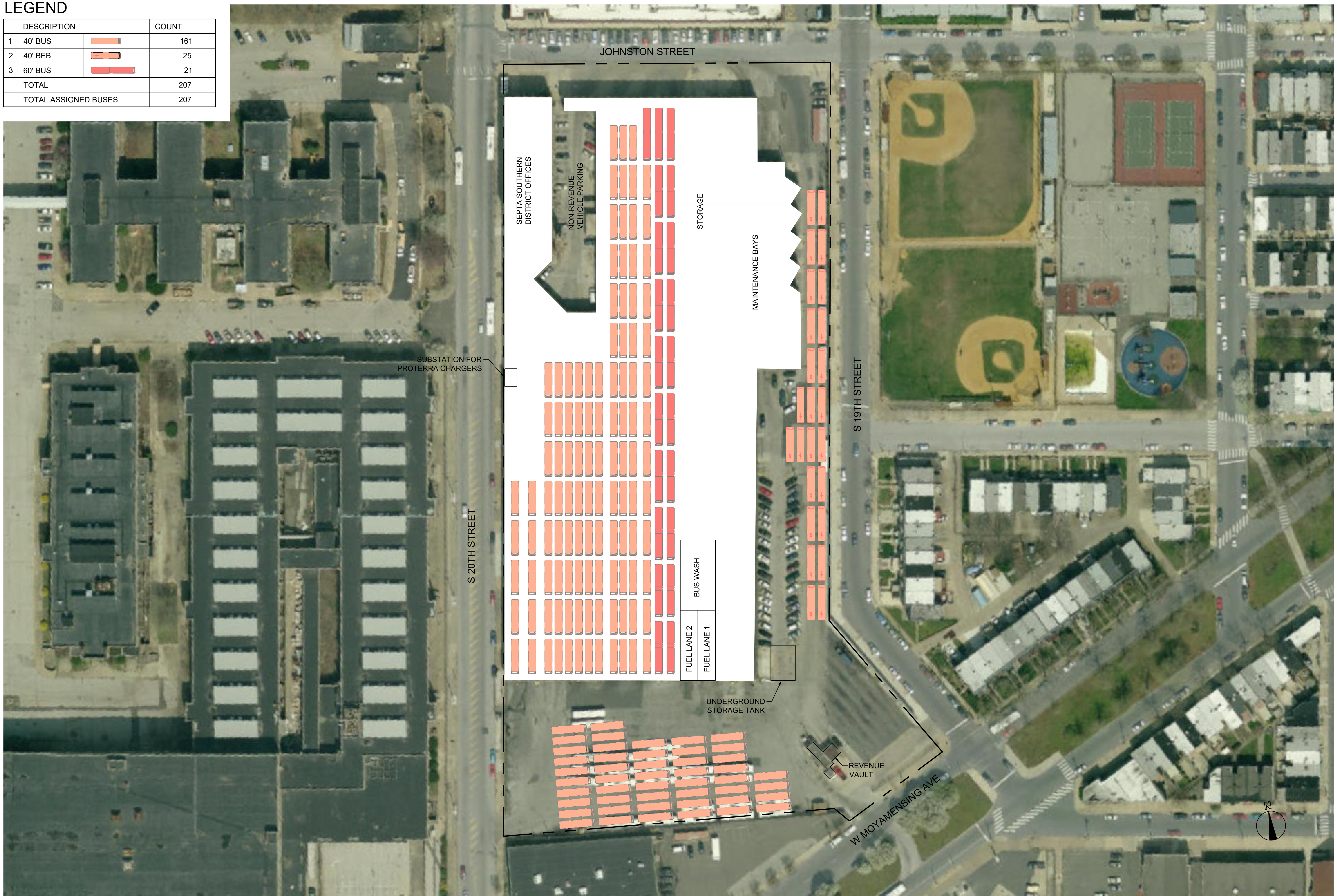
WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 STATION W/ CONTAINMENT WALLS

DRAWING NUMBER
FD01_1

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		161
2	40' BEB		25
3	60' BUS		21
	TOTAL		207
	TOTAL ASSIGNED BUSES		207



PROJECT NO.	30901231
DRAWN BY	JK
DATE	9/8/2022
SCALE	22x34 1" = 50' 11 X 17 1" = 100'

PROJECT TITLE
SEPTA DEPOT SOUTHERN

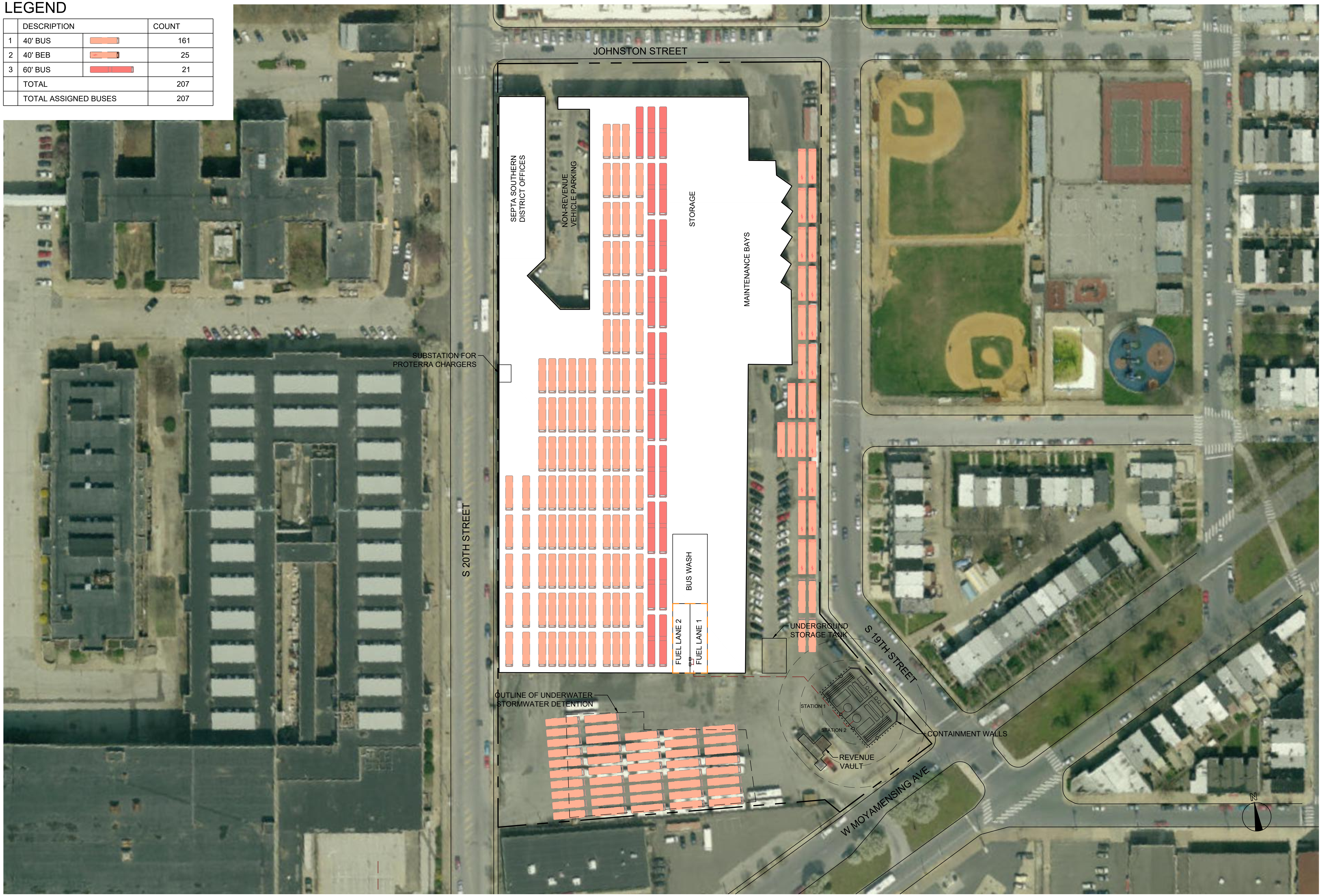
WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
EXISTING W/ AERIAL SOUTHERN

DRAWING NUMBER
EX 01

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		161
2	40' BEB		25
3	60' BUS		21
	TOTAL		207
	TOTAL ASSIGNED BUSES		207



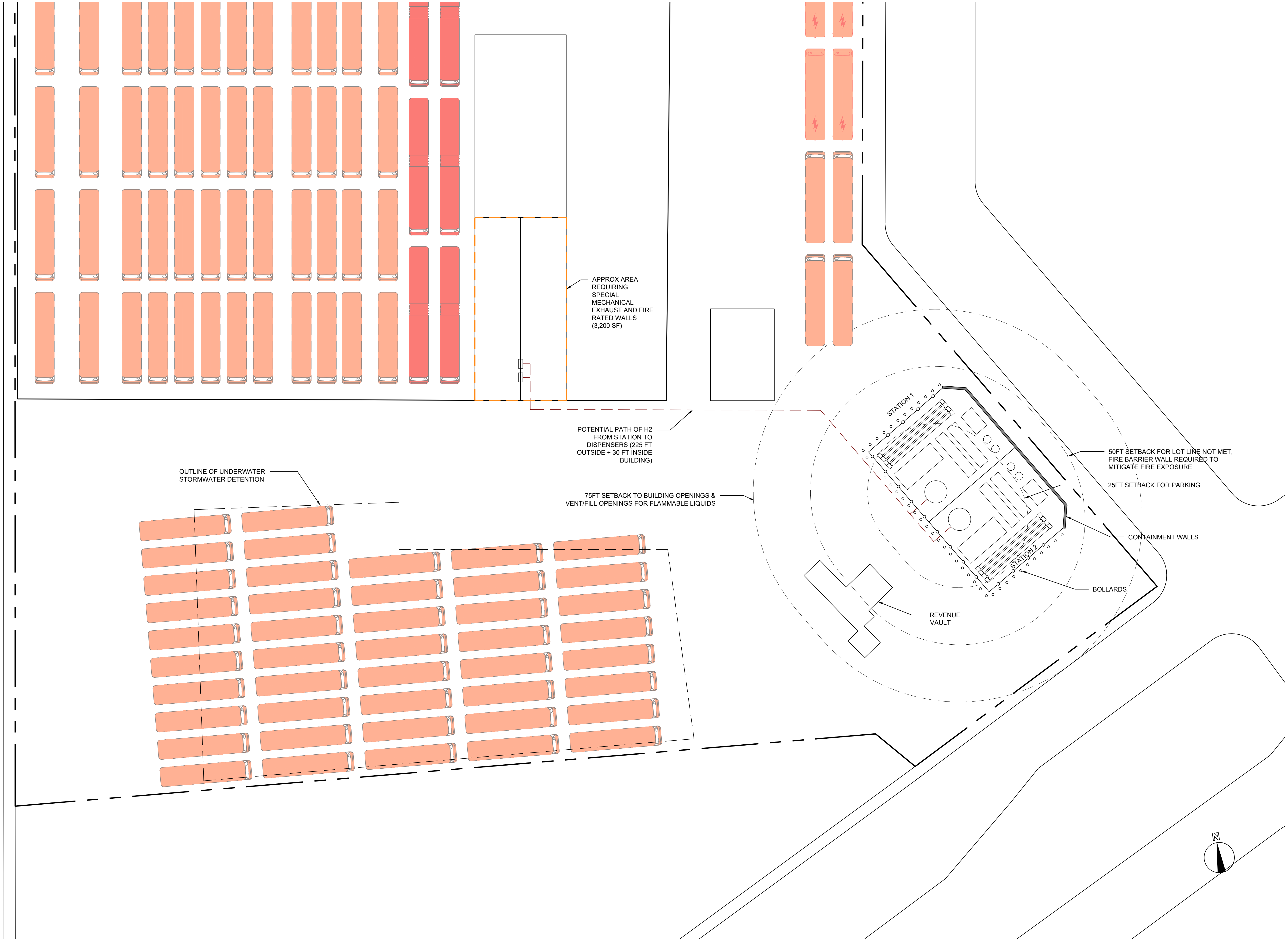
PROJECT NO.	30901231
DRAWN BY	JK
DATE	12/14/2022
SCALE	22x34 1" = 50' 11 X 17 1" = 100'

PROJECT TITLE
SEPTA DEPOT SOUTHERN

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 STATION W/ CONTAINMENT WALLS

DRAWING NUMBER
S01



PROJECT NO. 30901231

DRAWN BY JK

DATE 12/14/2022

SCALE 22x34 1" = 20'
11 X 17 1" = 40'

PROJECT TITLE
SEPTA DEPOT SOUTHERN

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 STATION W/ CONTAINMENT WALLS

DRAWING NUMBER
S01_1

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		145
	TOTAL		145
	TOTAL ASSIGNED BUSES		145

PROJECT NO. 30901231
DRAWN BY JK
DATE 7/27/2022
SCALE 22x34 1" = 60'; 11 X 17 1" = 120'

PROJECT TITLE
SEPTA VICTORY DEPOT

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
EXISTING W/ AERIAL VICTORY

DRAWING NUMBER
EX 01

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		138
	TOTAL		138
	TOTAL ASSIGNED BUSES		145

(17 BUSES TO BE RELOCATED)

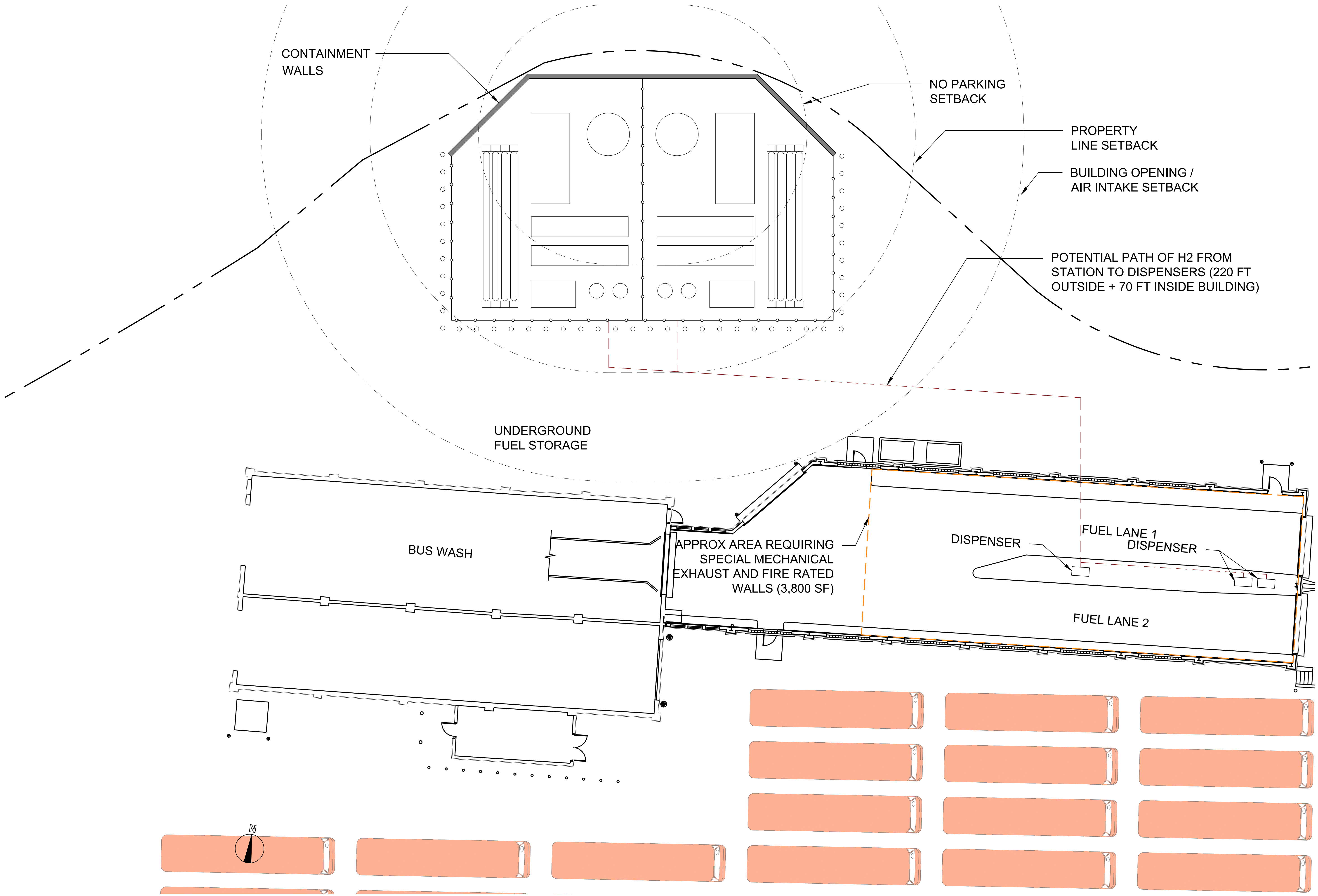
PROJECT NO.	30901231
DRAWN BY	JK
DATE	10/27/2022
SCALE	22x34 1" = 60' 11 X 17 1" = 120'

PROJECT TITLE
SEPTA VICTORY DEPOT

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 STATION W/ SETBACKS & CONTAINMENT WALLS

DRAWING NUMBER
V01



PROJECT NO. 30901231
DRAWN BY JK
DATE 11/01/2022
SCALE 22x34 1" = 10'
11 X 17 1" = 20'

PROJECT TITLE
SEPTA DEPOT VICTORY

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 STATIONS W/ SETBACKS & CONTAINMENT WALLS

DRAWING NUMBER
V01_1

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		134
	TOTAL		134
	TOTAL ASSIGNED BUSES		145

(21 BUSES TO BE RELOCATED)

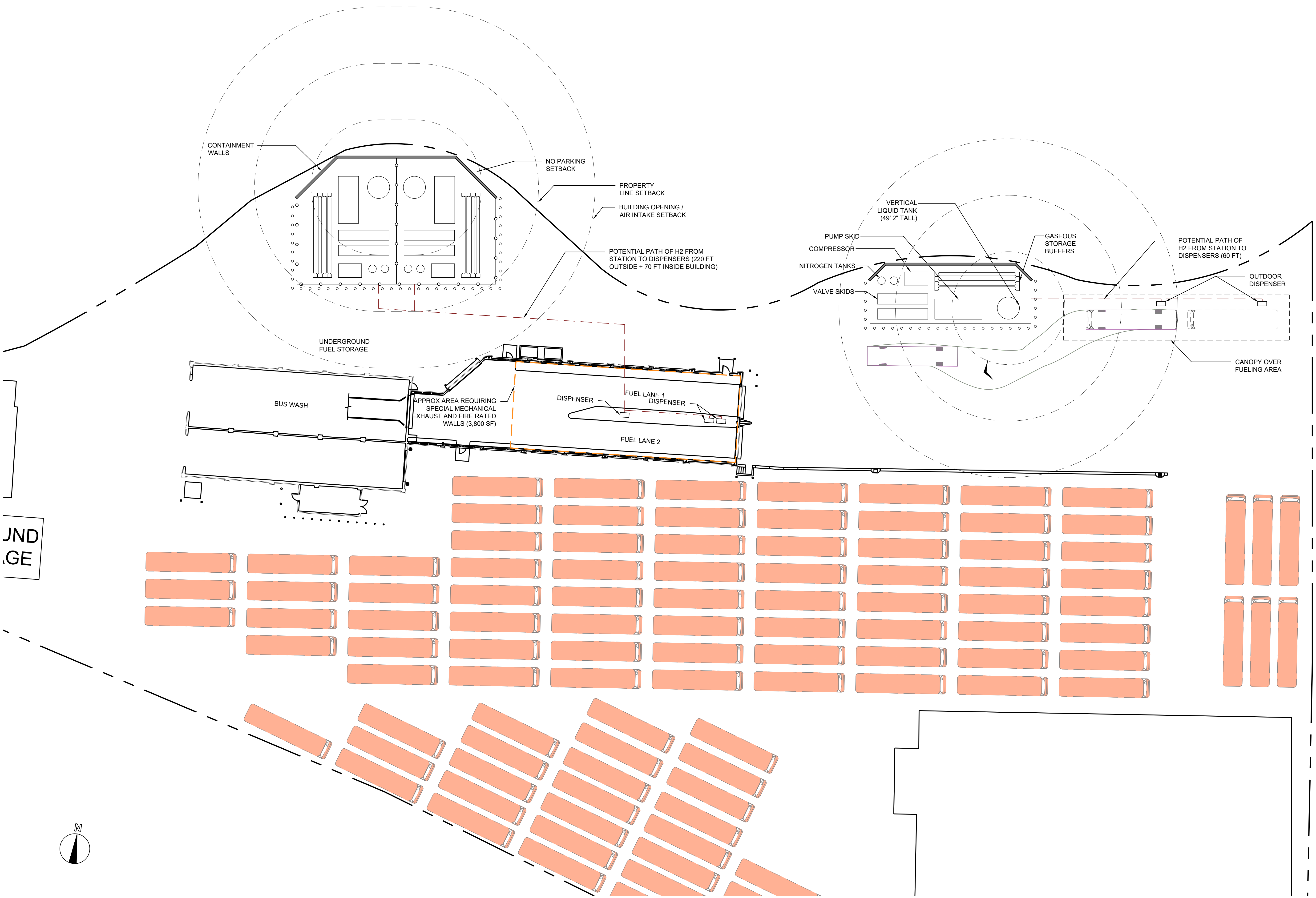
PROJECT NO.	30901231
DRAWN BY	JK
DATE	12/14/2022
SCALE	22x34 1" = 60' 11 X 17 1" = 120'

PROJECT TITLE
SEPTA VICTORY DEPOT

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 STATION W/ SETBACKS & CONTAINMENT WALLS

DRAWING NUMBER
V02



PROJECT NO.	30901231
DRAWN BY	JK
DATE	12/14/2022
SCALE	22x34 1" = 20' 11 X 17 1" = 40'

PROJECT TITLE

SEPTA DEPOT VICTORY

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE

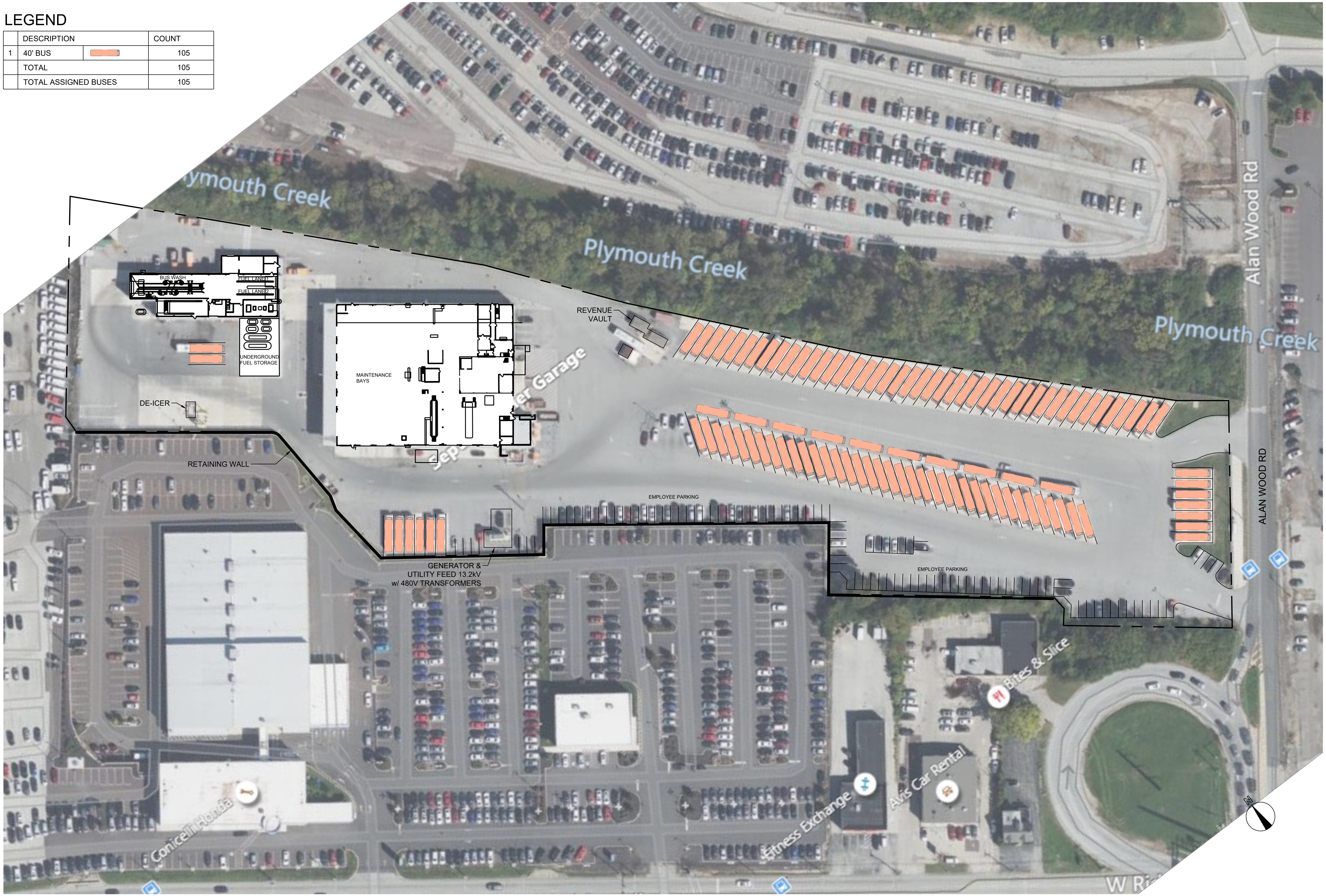
LH2 STATIONS FOR VICTORY AND CALLOWHILL

DRAWING NUMBER

V02_1

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		105
	TOTAL		105
	TOTAL ASSIGNED BUSES		105



PROJECT NO. 30901231
DRAWN BY JK
DATE 9/8/2022
SCALE 22x34 1" = 50'; 11 X 17 1" = 100'

PROJECT TITLE
SEPTA DEPOT FRONTIER

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
EXISTING W/ AERIAL FRONTIER

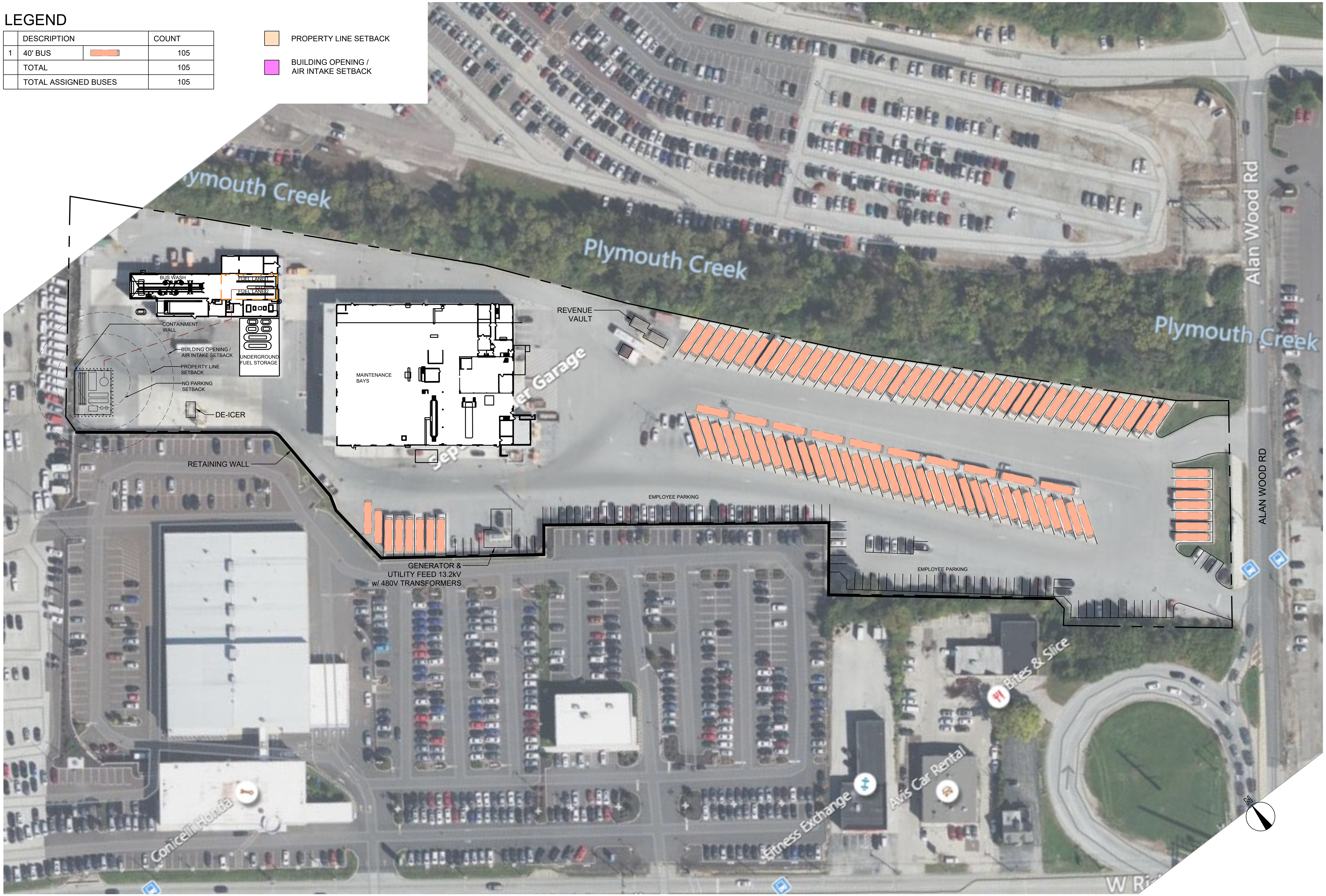
DRAWING NUMBER
EX 01

LEGEND

	DESCRIPTION		COUNT
1	40' BUS		105
	TOTAL		105
	TOTAL ASSIGNED BUSES		105

PROPERTY LINE SETBACK

BUILDING OPENING / AIR INTAKE SETBACK



PROJECT NO.	30901231
DRAWN BY	JK
DATE	11/01/2022
SCALE	22x34 1" = 50' 11 X 17 1" = 100'

PROJECT TITLE

SEPTA DEPOT FRONTIER

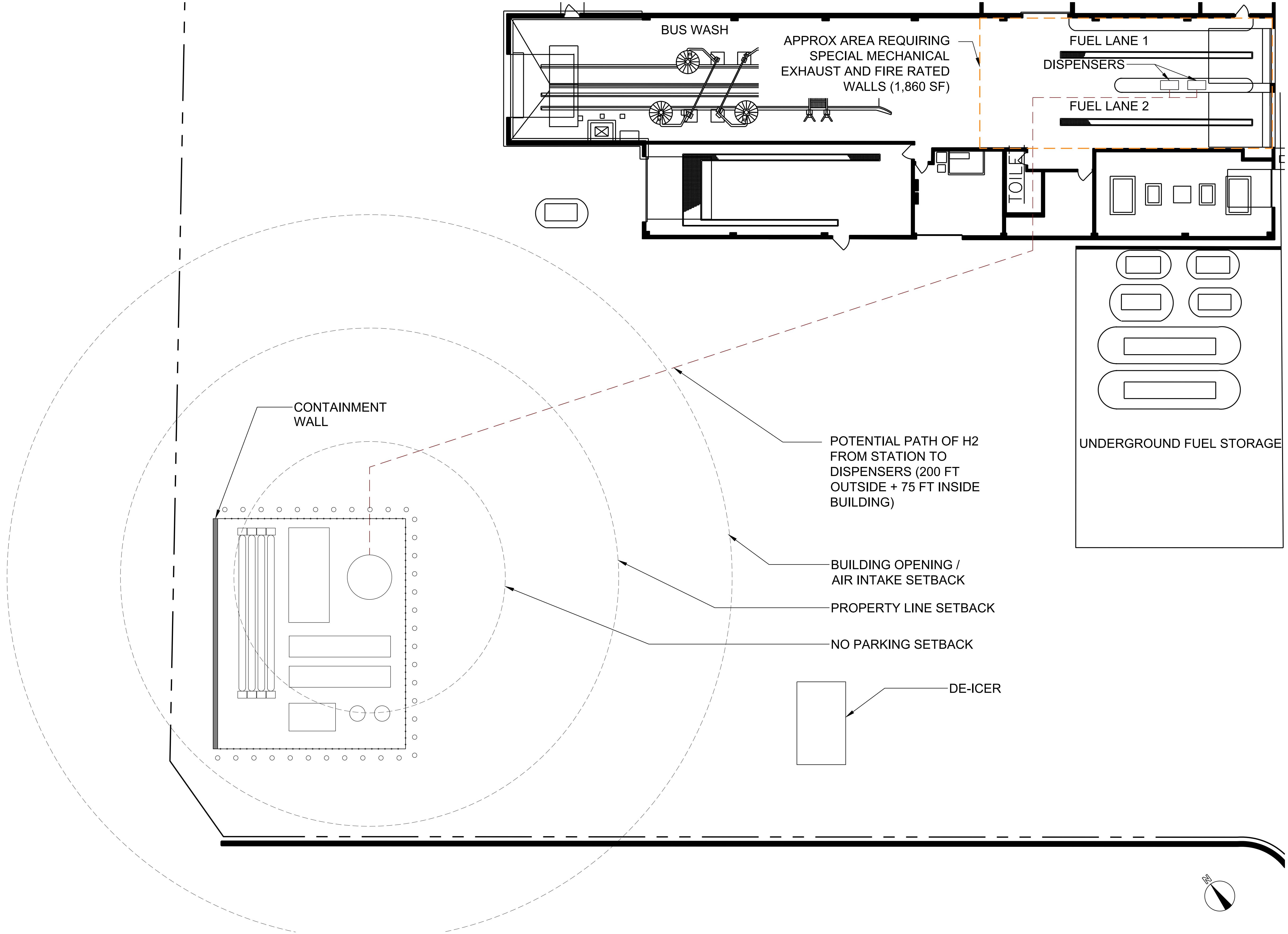
WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE

LH2 STATION W/ SETBACKS & CONTAINMENT WALLS

DRAWING NUMBER

F01



PROJECT NO. 30901231
DRAWN BY JK
DATE 11/01/2022
SCALE 22x34 1" = 50' 11 X 17 1" = 100'

PROJECT TITLE
SEPTA DEPOT FRONTIER

WSP USA Inc.
16200 PARK ROW
SUITE 200
HOUSTON, TEXAS 77084
TEL: (281) 589-5900
FAX: (281) 759-5164

DRAWING TITLE
LH2 STATION W/ SETBACKS & CONTAINMENT WALLS

DRAWING NUMBER
F01_1

APPENDIX D

HYDROGEN FUELING FACILITY COST ESTIMATES

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
COST ESTIMATE
MIDVALE DEPOT

CONSTRUCTION COSTS						
ITEM NO.	QUANTITY	UNIT		ITEM DESCRIPTION	UNIT PRICE	TOTAL
EXTERIOR UPGRADES AND H_2 EQUIPMENT						
1.01	3	EACH		LM-XL-35 STATION	$ 3,600,000.00	$ 10,800,000.00
1.02	4	EACH		DISPENSER	$ 5,350.00	$ 21,400.00
1.03	225	CY		CLASS AA CONCRETE 12"	$ 180.00	$ 40,500.00
1.04	285	CY		EXCAVATION AND BACKFILL	$ 90.00	$ 25,650.00
1.05	1,700	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, WEARING COURSE, 1 1/2" DEPTH	$ 36.00	$ 61,200.00
1.06	1,700	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, BASE COURSE, 6" DEPTH	$ 50.00	$ 85,000.00
1.07	1,700	SY		SUBBASE 6" DEPTH (NO. 2A)	$ 10.00	$ 17,000.00
1.08	550	LF		3" PVC PIPE	$ 20.00	$ 11,000.00
1.09	550	LF		1" STAINLESS STEEL PIPE	$ 40.00	$ 22,000.00
1.10	550	SF		INSULATION FOR PIPING	$ 9.00	$ 4,950.00
1.11	90	EACH		BOLLARD	$ 300.00	$ 27,000.00
1.13	450	LF		FENCING	$ 36.00	$ 16,200.00
					SUBTOTAL	$ 11,131,900.00
ELECTRICAL UPGRADES						
3.01	200	LF		1" DIRECT BURIAL CONDUIT	$ 3.00	$ 600.00
3.02	200	LF		AWG 10 UNDERGROUND CABLE, COPPER, 1 CONDUCTOR	$ 3.00	$ 600.00
3.03	3	EACH		CIRCUIT	$ 25,000.00	$ 75,000.00
3.04	1	LF		DISTRIBUTION GEAR (EATON 200A BREAKER PANEL)	$ 29,000.00	$ 29,000.00
3.05	1	LS		GENERATOR AND INCIDENTAL ITEMS	$ 1,500,000.00	$ 1,500,000.00
					SUBTOTAL	$ 1,605,200.00
H2 SENSORS AND ALARMS						
4.01	4	EACH		GASEOUS HYDROGEN SENSOR	$ 1,000.00	$ 4,000.00
4.02	1	LS		ALARM(S)	$ 2,500.00	$ 2,500.00
4.03	8	LS		TRIGGER FOR AUTOMATIC ROLL-DOWN DOORS	$ 1,000.00	$ 8,000.00
4.04	624	EACH		SPRINKLER, INCLUDING PIPING	$ 425.00	$ 265,200.00
4.05	4	EACH		FLAME DETECTION CAMERA	$ 7,500.00	$ 30,000.00
4.06	4	EACH		EXPLOSION PROOF CASING FOR CAMERA	$ 1,300.00	$ 5,200.00
4.07	1	EACH		CONTROLLER	$ 10,000.00	$ 10,000.00
4.08	4	EACH		ETON ESD BUTTONS	$ 100.00	$ 400.00
4.09	1	EACH		20-LB EXTINGUISHER	$ 325.00	$ 325.00
4.10	1	EACH		FIRE EXTINGUISHER CABINET	$ 350.00	$ 350.00
					SUBTOTAL	$ 325,975.00
					20% CONTINGENCY	$ 2,612,615.00
					MIDVALE DEPOT TOTAL	$ 15,675,690.00

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
COST ESTIMATE
ALLEGHENY FUELING AT MIDVALE DEPOT

CONSTRUCTION COSTS						
ITEM NO.	QUANTITY	UNIT		ITEM DESCRIPTION	UNIT PRICE	TOTAL
EXTERIOR UPGRADES AND H_2 EQUIPMENT						
1.01	1	EACH		LM-XL-35 STATION	$ 3,600,000.00	$ 3,600,000.00
1.02	2	EACH		DISPENSER	$ 5,350.00	$ 10,700.00
1.03	75	CY		CLASS AA CONCRETE 12"	$ 180.00	$ 13,500.00
1.04	95	CY		EXCAVATION AND BACKFILL	$ 90.00	$ 8,550.00
1.05	110	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, WEARING COURSE, 1 1/2" DEPTH	$ 36.00	$ 3,960.00
1.06	110	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, BASE COURSE, 6" DEPTH	$ 50.00	$ 5,500.00
1.07	110	SY		SUBBASE 6" DEPTH (NO. 2A)	$ 10.00	$ 1,100.00
1.08	255	LF		3" PVC PIPE	$ 20.00	$ 5,100.00
1.09	255	LF		1" STAINLESS STEEL PIPE	$ 40.00	$ 10,200.00
1.10	255	SF		INSULATION FOR PIPING	$ 9.00	$ 2,295.00
1.11	20	EACH		BOLLARD	$ 300.00	$ 6,000.00
1.13	130	LF		FENCING	$ 36.00	$ 4,680.00
1.17	1	LS		CANOPY AND FUELING ISLAND(S)	$ 200,000.00	$ 200,000.00
					SUBTOTAL	$ 3,871,585.00
ELECTRICAL UPGRADES						
3.01	1,500	LF		1" DIRECT BURIAL CONDUIT	$ 3.00	$ 4,500.00
3.02	1,500	LF		AWG 10 UNDERGROUND CABLE, COPPER, 1 CONDUCTOR	$ 3.00	$ 4,500.00
3.03	1	EACH		CIRCUIT	$ 25,000.00	$ 25,000.00
					SUBTOTAL	$ 34,000.00
H2 SENSORS AND ALARMS						
4.05	2	EACH		FLAME DETECTION CAMERA	$ 7,500.00	$ 15,000.00
4.06	2	EACH		EXPLOSION PROOF CASING FOR CAMERA	$ 1,300.00	$ 2,600.00
4.07	1	EACH		CONTROLLER	$ 10,000.00	$ 10,000.00
4.08	2	EACH		ETON ESD BUTTONS	$ 100.00	$ 200.00
4.09	1	EACH		20-LB EXTINGUISHER	$ 325.00	$ 325.00
4.10	1	EACH		FIRE EXTINGUISHER CABINET	$ 350.00	$ 350.00
					SUBTOTAL	$ 28,475.00
					20% CONTINGENCY	$ 786,812.00
					ALLEGHENY FUELING AT MIDVALE DEPOT TOTAL	$ 4,720,872.00

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
COST ESTIMATE
COMLY DEPOT

CONSTRUCTION COSTS					
ITEM NO.	QUANTITY	UNIT	ITEM DESCRIPTION	UNIT PRICE	TOTAL
EXTERIOR UPGRADES AND H_2 EQUIPMENT					
1.01	2	EACH	LM-XL-35 STATION	$ 3,600,000.00	$ 7,200,000.00
1.02	3	EACH	DISPENSER	$ 5,350.00	$ 16,050.00
1.03	160	CY	CLASS AA CONCRETE 12"	$ 180.00	$ 28,800.00
1.04	220	CY	EXCAVATION AND BACKFILL	$ 90.00	$ 19,800.00
1.05	175	SY	SUPERPAVE ASPHALT MIXTURE DESIGN, WEARING COURSE, 1 1/2" DEPTH	$ 36.00	$ 6,300.00
1.06	175	SY	SUPERPAVE ASPHALT MIXTURE DESIGN, BASE COURSE, 6" DEPTH	$ 50.00	$ 8,750.00
1.07	175	SY	SUBBASE 6" DEPTH (NO. 2A)	$ 10.00	$ 1,750.00
1.08	250	LF	3" PVC PIPE	$ 20.00	$ 5,000.00
1.09	250	LF	1" STAINLESS STEEL PIPE	$ 40.00	$ 10,000.00
1.10	250	SF	INSULATION FOR PIPING	$ 9.00	$ 2,250.00
1.11	45	EACH	BOLLARD	$ 300.00	$ 13,500.00
1.12	90	LF	CONTAINMENT WALL (8-FT HEIGHT)	$ 300.00	$ 27,000.00
1.13	220	LF	FENCING	$ 36.00	$ 7,920.00
1.16	24	SF	CLOSURE OF BUILDING OPENINGS	$ 60.00	$ 1,440.00
				SUBTOTAL	$ 7,348,560.00
INTERIOR UPGRADES					
2.01	10	EACH	DEFLAGRATION PANEL	$ 500.00	$ 5,000.00
2.02	4	EACH	ROLL DOWN DOOR	$ 9,500.00	$ 38,000.00
2.03	370	LF	INTERIOR WALLS, 2 HOUR FIRE RATED (12-FT HEIGHT)	$ 216.00	$ 79,920.00
2.04	2	EACH	FIRE DOOR	$ 1,800.00	$ 3,600.00
2.05	5,000	SF	MECHANICAL EXHAUST UPGRADES	$ 8.00	$ 40,000.00
				SUBTOTAL	$ 166,520.00
ELECTRICAL UPGRADES					
3.01	155	LF	1" DIRECT BURIAL CONDUIT	$ 3.00	$ 465.00
3.02	155	LF	AWG 10 UNDERGROUND CABLE, COPPER, 1 CONDUCTOR	$ 3.00	$ 465.00
3.03	2	EACH	CIRCUIT	$ 25,000.00	$ 50,000.00
3.04	1	LF	DISTRIBUTION GEAR (EATON 200A BREAKER PANEL)	$ 29,000.00	$ 29,000.00
3.05	1	LS	GENERATOR AND INCIDENTAL ITEMS	$ 1,500,000.00	$ 1,500,000.00
				SUBTOTAL	$ 1,579,930.00
H2 SENSORS AND ALARMS					
4.01	3	EACH	GASEOUS HYDROGEN SENSOR	$ 1,000.00	$ 3,000.00
4.02	1	LS	ALARM(S)	$ 2,500.00	$ 2,500.00
4.03	4	LS	TRIGGER FOR AUTOMATIC ROLL-DOWN DOORS	$ 1,000.00	$ 4,000.00
4.04	148	EACH	SPRINKLER, INCLUDING PIPING	$ 425.00	$ 62,900.00
4.05	3	EACH	FLAME DETECTION CAMERA	$ 7,500.00	$ 22,500.00
4.06	3	EACH	EXPLOSION PROOF CASING FOR CAMERA	$ 1,300.00	$ 3,900.00
4.07	1	EACH	CONTROLLER	$ 10,000.00	$ 10,000.00
4.08	3	EACH	ETON ESD BUTTONS	$ 100.00	$ 300.00
4.09	1	EACH	20-LB EXTINGUISHER	$ 325.00	$ 325.00
4.10	1	EACH	FIRE EXTINGUISHER CABINET	$ 350.00	$ 350.00
				SUBTOTAL	$ 109,775.00
				20% CONTINGENCY	$ 1,840,957.00
				COMLY DEPOT TOTAL	$ 11,045,742.00

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
COST ESTIMATE
FRANKFORD DEPOT

CONSTRUCTION COSTS

ITEM NO.	QUANTITY	UNIT		ITEM DESCRIPTION	UNIT PRICE	TOTAL
EXTERIOR UPGRADES AND H_2 EQUIPMENT						
1.01	1	EACH		LM-XL-35 STATION	$ 3,600,000.00	$ 3,600,000.00
1.02	2	EACH		DISPENSER	$ 5,350.00	$ 10,700.00
1.03	80	CY		CLASS AA CONCRETE 12"	$ 180.00	$ 14,400.00
1.04	215	CY		EXCAVATION AND BACKFILL	$ 90.00	$ 19,350.00
1.05	185	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, WEARING COURSE, 1 1/2" DEPTH	$ 36.00	$ 6,660.00
1.06	185	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, BASE COURSE, 6" DEPTH	$ 50.00	$ 9,250.00
1.07	185	SY		SUBBASE 6" DEPTH (NO. 2A)	$ 10.00	$ 1,850.00
1.08	605	LF		3" PVC PIPE	$ 20.00	$ 12,100.00
1.09	605	LF		1" STAINLESS STEEL PIPE	$ 40.00	$ 24,200.00
1.10	605	SF		INSULATION FOR PIPING	$ 9.00	$ 5,445.00
1.11	24	EACH		BOLLARD	$ 300.00	$ 7,200.00
1.12	95	LF		CONTAINMENT WALL (8-FT HEIGHT)	$ 300.00	$ 28,500.00
1.13	95	LF		FENCING	$ 36.00	$ 3,420.00
1.14	1	LS		DEMOLITION OF EXISTING PASSENGER WAITING AREA	$ 10,000.00	$ 10,000.00
1.15	1	LS		PASSENGER WAITING AREA AND SEATING	$ 16,000.00	$ 16,000.00
					SUBTOTAL	$ 3,769,075.00
INTERIOR UPGRADES						
2.01	9	EACH		DEFLAGRATION PANEL	$ 500.00	$ 4,300.00
2.02	4	EACH		ROLL DOWN DOOR	$ 9,500.00	$ 38,000.00
2.03	370	LF		INTERIOR WALLS, 2 HOUR FIRE RATED (12-FT HEIGHT)	$ 216.00	$ 79,920.00
2.04	2	EACH		FIRE DOOR	$ 1,800.00	$ 3,600.00
2.05	4,300	SF		MECHANICAL EXHAUST UPGRADES	$ 8.00	$ 34,400.00
					SUBTOTAL	$ 160,220.00
ELECTRICAL UPGRADES						
3.01	1,100	LF		1" DIRECT BURIAL CONDUIT	$ 3.00	$ 3,300.00
3.02	1,100	LF		AWG 10 UNDERGROUND CABLE, COPPER, 1 CONDUCTOR	$ 3.00	$ 3,300.00
3.03	1	EACH		CIRCUIT	$ 25,000.00	$ 25,000.00
3.04	1	LF		DISTRIBUTION GEAR (EATON 200A BREAKER PANEL)	$ 29,000.00	$ 29,000.00
3.05	1	LS		GENERATOR AND INCIDENTAL ITEMS	$ 1,500,000.00	$ 1,500,000.00
					SUBTOTAL	$ 1,560,600.00
H2 SENSORS AND ALARMS						
4.01	2	EACH		GASEOUS HYDROGEN SENSOR	$ 1,000.00	$ 2,000.00
4.02	1	LS		ALARM(S)	$ 2,500.00	$ 2,500.00
4.03	4	LS		TRIGGER FOR AUTOMATIC ROLL-DOWN DOORS	$ 1,000.00	$ 4,000.00
4.04	85	EACH		SPRINKLER, INCLUDING PIPING	$ 425.00	$ 36,125.00
4.05	2	EACH		FLAME DETECTION CAMERA	$ 7,500.00	$ 15,000.00
4.06	2	EACH		EXPLOSION PROOF CASING FOR CAMERA	$ 1,300.00	$ 2,600.00
4.07	1	EACH		CONTROLLER	$ 10,000.00	$ 10,000.00
4.08	2	EACH		ETON ESD BUTTONS	$ 100.00	$ 200.00
4.09	1	EACH		20-LB EXTINGUISHER	$ 325.00	$ 325.00
4.10	1	EACH		FIRE EXTINGUISHER CABINET	$ 350.00	$ 350.00
					SUBTOTAL	$ 73,100.00
					20% CONTINGENCY	$ 1,112,599.00
					FRANKFORD DEPOT TOTAL	$ 6,675,594.00

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
COST ESTIMATE
FRONTIER DEPOT

CONSTRUCTION COSTS

ITEM NO.	QUANTITY	UNIT		ITEM DESCRIPTION	UNIT PRICE	TOTAL
EXTERIOR UPGRADES AND H_2 EQUIPMENT						
1.01	1	EACH		LM-XL-35 STATION	$ 3,600,000.00	$ 3,600,000.00
1.02	2	EACH		DISPENSER	$ 5,350.00	$ 10,700.00
1.03	80	CY		CLASS AA CONCRETE 12"	$ 180.00	$ 14,400.00
1.04	105	CY		EXCAVATION AND BACKFILL	$ 90.00	$ 9,450.00
1.05	75	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, WEARING COURSE, 1 1/2" DEPTH	$ 36.00	$ 2,700.00
1.06	75	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, BASE COURSE, 6" DEPTH	$ 50.00	$ 3,750.00
1.07	75	SY		SUBBASE 6" DEPTH (NO. 2A)	$ 10.00	$ 750.00
1.08	250	LF		3" PVC PIPE	$ 20.00	$ 5,000.00
1.09	250	LF		1" STAINLESS STEEL PIPE	$ 40.00	$ 10,000.00
1.10	250	SF		INSULATION FOR PIPING	$ 9.00	$ 2,250.00
1.11	36	EACH		BOLLARD	$ 300.00	$ 10,800.00
1.12	55	LF		CONTAINMENT WALL (8-FT HEIGHT)	$ 300.00	$ 16,500.00
1.13	140	LF		FENCING	$ 36.00	$ 5,040.00
					SUBTOTAL	**$ 3,691,340.00**
INTERIOR UPGRADES						
2.01	4	EACH		DEFLAGRATION PANEL	$ 500.00	$ 1,860.00
2.02	4	EACH		ROLL DOWN DOOR	$ 9,500.00	$ 38,000.00
2.03	330	LF		INTERIOR WALLS, 2 HOUR FIRE RATED (12-FT HEIGHT)	$ 216.00	$ 71,280.00
2.04	2	EACH		FIRE DOOR	$ 1,800.00	$ 3,600.00
2.05	1,860	SF		MECHANICAL EXHAUST UPGRADES	$ 8.00	$ 14,880.00
					SUBTOTAL	**$ 129,620.00**
ELECTRICAL UPGRADES						
3.01	510	LF		1" DIRECT BURIAL CONDUIT	$ 3.00	$ 1,530.00
3.02	510	LF		AWG 10 UNDERGROUND CABLE, COPPER, 1 CONDUCTOR	$ 3.00	$ 1,530.00
3.03	1	EACH		CIRCUIT	$ 25,000.00	$ 25,000.00
3.04	1	LF		DISTRIBUTION GEAR (EATON 200A BREAKER PANEL)	$ 29,000.00	$ 29,000.00
3.05	1	LS		GENERATOR AND INCIDENTAL ITEMS	$ 1,500,000.00	$ 1,500,000.00
					SUBTOTAL	**$ 1,557,060.00**
H2 SENSORS AND ALARMS						
4.01	2	EACH		GASEOUS HYDROGEN SENSOR	$ 1,000.00	$ 2,000.00
4.02	1	LS		ALARM(S)	$ 2,500.00	$ 2,500.00
4.03	4	LS		TRIGGER FOR AUTOMATIC ROLL-DOWN DOORS	$ 1,000.00	$ 4,000.00
4.04	21	EACH		SPRINKLER, INCLUDING PIPING	$ 425.00	$ 8,925.00
4.05	2	EACH		FLAME DETECTION CAMERA	$ 7,500.00	$ 15,000.00
4.06	2	EACH		EXPLOSION PROOF CASING FOR CAMERA	$ 1,300.00	$ 2,600.00
4.07	1	EACH		CONTROLLER	$ 10,000.00	$ 10,000.00
4.08	2	EACH		ETON ESD BUTTONS	$ 100.00	$ 200.00
4.09	1	EACH		20-LB EXTINGUISHER	$ 325.00	$ 325.00
4.10	1	EACH		FIRE EXTINGUISHER CABINET	$ 350.00	$ 350.00
					SUBTOTAL	**$ 45,900.00**
					20% CONTINGENCY	**$ 1,084,784.00**
					FRONTIER DEPOT TOTAL	**$ 6,508,704.00**

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
COST ESTIMATE
SOUTHERN DEPOT

CONSTRUCTION COSTS

ITEM NO.	QUANTITY	UNIT		ITEM DESCRIPTION	UNIT PRICE	TOTAL
EXTERIOR UPGRADES AND H_2 EQUIPMENT						
1.01	2	EACH		LM-XL-35 STATION	$ 3,600,000.00	$ 7,200,000.00
1.02	3	EACH		DISPENSER	$ 5,350.00	$ 16,050.00
1.03	150	CY		CLASS AA CONCRETE 12"	$ 180.00	$ 27,000.00
1.04	200	CY		EXCAVATION AND BACKFILL	$ 90.00	$ 18,000.00
1.05	100	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, WEARING COURSE, 1 1/2" DEPTH	$ 36.00	$ 3,600.00
1.06	100	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, BASE COURSE, 6" DEPTH	$ 50.00	$ 5,000.00
1.07	100	SY		SUBBASE 6" DEPTH (NO. 2A)	$ 10.00	$ 1,000.00
1.08	625	LF		3" PVC PIPE	$ 20.00	$ 12,500.00
1.09	624	LF		1" STAINLESS STEEL PIPE	$ 40.00	$ 24,960.00
1.10	625	SF		INSULATION FOR PIPING	$ 9.00	$ 5,625.00
1.11	45	EACH		BOLLARD	$ 300.00	$ 13,500.00
1.12	90	LF		CONTAINMENT WALL (8-FT HEIGHT)	$ 300.00	$ 27,000.00
1.13	220	LF		FENCING	$ 36.00	$ 7,920.00
					SUBTOTAL	**$ 7,362,155.00**
INTERIOR UPGRADES						
2.01	6	EACH		DEFLAGRATION PANEL	$ 500.00	$ 3,200.00
2.02	4	EACH		ROLL DOWN DOOR	$ 9,500.00	$ 38,000.00
2.03	330	LF		INTERIOR WALLS, 2 HOUR FIRE RATED (12-FT HEIGHT)	$ 216.00	$ 71,280.00
2.04	2	EACH		FIRE DOOR	$ 1,800.00	$ 3,600.00
2.05	3,200	SF		MECHANICAL EXHAUST UPGRADES	$ 8.00	$ 25,600.00
					SUBTOTAL	**$ 141,680.00**
ELECTRICAL UPGRADES						
3.01	725	LF		1" DIRECT BURIAL CONDUIT	$ 3.00	$ 2,175.00
3.02	725	LF		AWG 10 UNDERGROUND CABLE, COPPER, 1 CONDUCTOR	$ 3.00	$ 2,175.00
3.03	2	EACH		CIRCUIT	$ 25,000.00	$ 50,000.00
3.04	1	LF		DISTRIBUTION GEAR (EATON 200A BREAKER PANEL)	$ 29,000.00	$ 29,000.00
3.05	1	LS		GENERATOR AND INCIDENTAL ITEMS	$ 1,500,000.00	$ 1,500,000.00
3.06	1	LS		TRANSFORMER UPGRADE	$ 25,000.00	$ 25,000.00
					SUBTOTAL	**$ 1,608,350.00**
H2 SENSORS AND ALARMS						
4.01	3	EACH		GASEOUS HYDROGEN SENSOR	$ 1,000.00	$ 3,000.00
4.02	1	LS		ALARM(S)	$ 2,500.00	$ 2,500.00
4.03	4	LS		TRIGGER FOR AUTOMATIC ROLL-DOWN DOORS	$ 1,000.00	$ 4,000.00
4.04	200	EACH		SPRINKLER, INCLUDING PIPING	$ 425.00	$ 85,000.00
4.05	3	EACH		FLAME DETECTION CAMERA	$ 7,500.00	$ 22,500.00
4.06	3	EACH		EXPLOSION PROOF CASING FOR CAMERA	$ 1,300.00	$ 3,900.00
4.07	1	EACH		CONTROLLER	$ 10,000.00	$ 10,000.00
4.08	3	EACH		ETON ESD BUTTONS	$ 100.00	$ 300.00
4.09	1	EACH		20-LB EXTINGUISHER	$ 325.00	$ 325.00
4.10	1	EACH		FIRE EXTINGUISHER CABINET	$ 350.00	$ 350.00
					SUBTOTAL	**$ 131,875.00**
					20% CONTINGENCY	**$ 1,848,812.00**
					SOUTHERN DEPOT TOTAL	**$ 11,092,872.00**

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
COST ESTIMATE
VICTORY DEPOT

CONSTRUCTION COSTS

ITEM NO.	QUANTITY	UNIT		ITEM DESCRIPTION	UNIT PRICE	TOTAL
EXTERIOR UPGRADES AND H_2 EQUIPMENT						
1.01	2	EACH		LM-XL-35 STATION	$ 3,600,000.00	$ 7,200,000.00
1.02	3	EACH		DISPENSER	$ 5,350.00	$ 16,050.00
1.03	150	CY		CLASS AA CONCRETE 12"	$ 180.00	$ 27,000.00
1.04	175	CY		EXCAVATION AND BACKFILL	$ 90.00	$ 15,750.00
1.05	80	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, WEARING COURSE, 1 1/2" DEPTH	$ 36.00	$ 2,880.00
1.06	80	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, BASE COURSE, 6" DEPTH	$ 50.00	$ 4,000.00
1.07	80	SY		SUBBASE 6" DEPTH (NO. 2A)	$ 10.00	$ 800.00
1.08	250	LF		3" PVC PIPE	$ 20.00	$ 5,000.00
1.09	250	LF		1" STAINLESS STEEL PIPE	$ 40.00	$ 10,000.00
1.10	250	SF		INSULATION FOR PIPING	$ 9.00	$ 2,250.00
1.11	45	EACH		BOLLARD	$ 300.00	$ -
1.12	110	LF		CONTAINMENT WALL (8-FT HEIGHT)	$ 300.00	$ 33,000.00
1.13	230	LF		FENCING	$ 36.00	$ 8,280.00
					SUBTOTAL	**$ 7,325,010.00**
INTERIOR UPGRADES						
2.01	8	EACH		DEFLAGRATION PANEL	$ 500.00	$ 3,800.00
2.02	4	EACH		ROLL DOWN DOOR	$ 9,500.00	$ 38,000.00
2.03	280	LF		INTERIOR WALLS, 2 HOUR FIRE RATED (12-FT HEIGHT)	$ 216.00	$ 60,480.00
2.04	2	EACH		FIRE DOOR	$ 1,800.00	$ 3,600.00
2.05	3,800	SF		MECHANICAL EXHAUST UPGRADES	$ 8.00	$ 30,400.00
					SUBTOTAL	**$ 136,280.00**
ELECTRICAL UPGRADES						
3.01	510	LF		1" DIRECT BURIAL CONDUIT	$ 3.00	$ 1,530.00
3.02	510	LF		AWG 10 UNDERGROUND CABLE, COPPER, 1 CONDUCTOR	$ 3.00	$ 1,530.00
3.03	2	EACH		CIRCUIT	$ 25,000.00	$ 50,000.00
3.04	1	LF		DISTRIBUTION GEAR (EATON 200A BREAKER PANEL)	$ 29,000.00	$ 29,000.00
3.05	1	LS		GENERATOR AND INCIDENTAL ITEMS	$ 1,500,000.00	$ 1,500,000.00
3.06	1	LS		TRANSFORMER UPGRADE	$ 25,000.00	$ 25,000.00
					SUBTOTAL	**$ 1,607,060.00**
H2 SENSORS AND ALARMS						
4.01	3	EACH		GASEOUS HYDROGEN SENSOR	$ 1,000.00	$ 3,000.00
4.02	1	LS		ALARM(S)	$ 2,500.00	$ 2,500.00
4.03	4	LS		TRIGGER FOR AUTOMATIC ROLL-DOWN DOORS	$ 1,000.00	$ 4,000.00
4.04	36	EACH		SPRINKLER, INCLUDING PIPING	$ 425.00	$ 15,300.00
4.05	3	EACH		FLAME DETECTION CAMERA	$ 7,500.00	$ 22,500.00
4.06	3	EACH		EXPLOSION PROOF CASING FOR CAMERA	$ 1,300.00	$ 3,900.00
4.07	1	EACH		CONTROLLER	$ 10,000.00	$ 10,000.00
4.08	3	EACH		ETON ESD BUTTONS	$ 100.00	$ 300.00
4.09	1	EACH		20-LB EXTINGUISHER	$ 325.00	$ 325.00
4.10	1	EACH		FIRE EXTINGUISHER CABINET	$ 350.00	$ 350.00
					SUBTOTAL	**$ 62,175.00**
					20% CONTINGENCY	**$ 1,826,105.00**
					VICTORY DEPOT TOTAL	**$ 10,956,630.00**

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
COST ESTIMATE
CALLOWHILL FUELING AT VICTORY DEPOT

CONSTRUCTION COSTS

ITEM NO.	QUANTITY	UNIT		ITEM DESCRIPTION	UNIT PRICE	TOTAL
EXTERIOR UPGRADES AND H_2 EQUIPMENT						
1.01	1	EACH		LM-XL-35 STATION	$ 3,600,000.00	$ 3,600,000.00
1.02	2	EACH		DISPENSER	$ 5,350.00	$ 10,700.00
1.03	150	CY		CLASS AA CONCRETE 12"	$ 180.00	$ 27,000.00
1.04	105	CY		EXCAVATION AND BACKFILL	$ 90.00	$ 9,450.00
1.05	95	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, WEARING COURSE, 1 1/2" DEPTH	$ 36.00	$ 3,420.00
1.06	95	SY		SUPERPAVE ASPHALT MIXTURE DESIGN, BASE COURSE, 6" DEPTH	$ 50.00	$ 4,750.00
1.07	95	SY		SUBBASE 6" DEPTH (NO. 2A)	$ 10.00	$ 950.00
1.08	235	LF		3" PVC PIPE	$ 20.00	$ 4,700.00
1.09	235	LF		1" STAINLESS STEEL PIPE	$ 40.00	$ 9,400.00
1.10	235	SF		INSULATION FOR PIPING	$ 9.00	$ 2,115.00
1.11	30	EACH		BOLLARD	$ 300.00	$ 9,000.00
1.12	85	LF		CONTAINMENT WALL (8-FT HEIGHT)	$ 300.00	$ 25,500.00
1.13	110	LF		FENCING	$ 36.00	$ 3,960.00
1.17	1	LS		CANOPY AND FUELING ISLAND(S)	$ 200,000.00	$ 200,000.00
					SUBTOTAL	**$ 3,910,945.00**
ELECTRICAL UPGRADES						
3.01	100	LF		1" DIRECT BURIAL CONDUIT	$ 3.00	$ 300.00
3.02	100	LF		AWG 10 UNDERGROUND CABLE, COPPER, 1 CONDUCTOR	$ 3.00	$ 300.00
3.03	1	EACH		CIRCUIT	$ 25,000.00	$ 25,000.00
					SUBTOTAL	**$ 25,600.00**
H2 SENSORS AND ALARMS						
4.05	2	EACH		FLAME DETECTION CAMERA	$ 7,500.00	$ 15,000.00
4.06	2	EACH		EXPLOSION PROOF CASING FOR CAMERA	$ 1,300.00	$ 2,600.00
4.07	2	EACH		CONTROLLER	$ 10,000.00	$ 20,000.00
4.08	2	EACH		ETON ESD BUTTONS	$ 100.00	$ 200.00
4.09	1	EACH		20-LB EXTINGUISHER	$ 325.00	$ 325.00
4.1	1	EACH		FIRE EXTINGUISHER CABINET	$ 350.00	$ 350.00
					SUBTOTAL	**$ 38,475.00**
					20% CONTINGENCY	**$ 795,004.00**
					CALLOWHILL FUELING AT VICTORY DEPOT TOTAL	**$ 4,770,024.00**

APPENDIX E

HYDROGEN AND EQUIPMENT DEMANDS

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
VOLUME ANALYSIS
HYDROGEN FUEL AND EQUIPMENT DEMAND

DEPOT	Current Operations w/ Diesel Buses					
	Annual miles	AVG MPG	Week-day Peak Buses	Average per Bus [1]		Peak Pull-in
				mi/day	gal/day	Buses/hr
Midvale	8,859,300	3.8	214	128	33.7	66
Allegheny (satellite)	3,169,137	3.1	88	111	36.0	19
Comly	5,373,869	4.5	125	133	29.6	26
Frankford	3,626,991	4.3	121	93	21.6	25
Victory	6,515,927	5.0	121	167	33.3	26
Callowhill (satellite)	5,348,592	4.0	141	117	29.4	31
Southern	5,448,088	3.6	144	117	32.5	31
Frontier	5,174,442	5.3	81	198	37.3	17

DEPOT	HYDROGEN USE [2]		
	AVG/bus per day kg	Total per day kg	Miniumum H_2 Deliveries per Week [5]
Midvale	24.3	5,191	10
Allegheny (satellite)	25.9	2,276	5
Comly	21.3	2,659	5
Frankford	15.5	1,878	4
Victory	24.0	2,902	6
Callowhill (satellite)	21.1	2,978	6
Southern	23.4	3,370	7
Frontier	26.8	2,174	4

DEPOT	Hydrogen Fueling [4]		Station Design Basis[5]		
			Required Stations	Required Dispensers	Days H_2 Storage
	Buses/hr	kg/hr	Num	Num	15,000 gal tank
Midvale	22	534	3	4	1.56
Allegheny (satellite)	9	233	1	2	1.19
Comly	16	341	2	3	2.03
Frankford	16	249	1	2	1.44
Victory	16	384	2	3	1.86
Callowhill (satellite)	18	381	1	2	1.15
Southern	18	422	2	3	1.60
Frontier	11	296	1	2	1.24

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
VOLUME ANALYSIS
HYDROGEN FUEL AND EQUIPMENT DEMAND

[1] Weighted days/yr 323

Assumes 60% weekend miles vs weekday

Calculated daily fuel use is generally consistent with current diesel fuel delivery volumes

[2] Fuel Energy Content

Fuel	Unit	Energy (HHV) btu/unit	Engine Efficiency	Usable Energy btu/unit
DIESEL	gal	138,490	35%	48,472
HYDROGEN	kg	134,785	50%	67,393

[3] LH2 tanker volume 3,400 kg (usable)

[4] Daily fueling window 8 hours (Comly, Frankford, Victory, Callowhill, Southern, Frontier)

10 hours (Midvale, Allegheny)

[5] Liquid hydrogen station

	15,000 gal Tank
Max Liquid Storage (kg)	2,700
Max Dispensers per station	2
Max H2 per Dispenser (kg/hr)	150

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
VOLUME ANALYSIS
HYDROGEN FUEL AND EQUIPMENT DEMAND

Equation 1: Average daily mileage per bus.

$$AVERAGE\ DAILY\ MILEAGE\ PER\ BUS = \frac{ANNUAL\ MILES\ TRAVELED / WEEKDAY\ PEAK\ BUSES}{WEIGHTED\ DAYS\ PER\ YEAR}$$

Equation 2: Average daily diesel fuel use per bus.

$$AVERAGE\ DAILY\ DIESEL\ FUEL\ USE\ PER\ BUS = \frac{AVERAGE\ DAILY\ MILEAGE\ PER\ BUS}{AVERAGE\ MPG}$$

Equation 3: Average daily hydrogen fuel use per bus.

$$AVG.\ DAILY\ H_2\ USE\ PER\ BUS(kg) = \frac{AVG.\ DAILY\ DIESEL\ FUEL\ USE\ PER\ BUS \times \frac{BTU}{GALLONS\ DIESEL\ FUEL}}{\frac{BTU}{kg\ H_2}}$$

Equation 4: Total hydrogen use per day, per depot.

$$TOTAL\ H_2\ USE\ PER\ DAY\ (kg) = AVG.\ DAILY\ H_2\ USE\ PER\ BUS\ (kg) \times WEEKDAY\ PEAK\ BUSES$$

Equation 5: Number of stations required.

$$\#\ OF\ STATIONS\ REQUIRED = \frac{H_2\ FUELING\ \left({}^{kg}/_{hr}\right)}{\#H_2\ DISPENSERS\ PER\ STATION \times MAX.\ H_2\ PER\ DISPENSER\ \left({}^{kg}/_{hr}\right)}$$

Equation 6: Number of dispensers required.

$$\#\ OF\ DISPENSERS\ REQUIRED = \frac{H_2\ FUELING\ \left({}^{kg}/_{hr}\right)}{MAX.\ H_2\ PER\ DISPENSER\ \left({}^{kg}/_{hr}\right)}$$

Equation 7: Days of H_2 storage.

$$DAYS\ OF\ H_2\ STORAGE = \frac{\#\ OF\ STATIONS \times STORAGE\ CAPACITY(kg)}{TOTAL\ DEPOT\ H_2\ USE, PER\ DAY}$$

APPENDIX F

ENERGY DEMANDS

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
ELECTRICAL CAPACITY ANALYSIS
ENERGY DEMAND

Energy Demands of FCEBs

Depot	Existing Connected Load	Number of H^2 Stations @350 kW	Additional Connected Load of H2 Stations	Total Required Connected Load
Midvale	800 kW	3	1050 kW	1850 kW
Allegheny (satellite)*	-	1	350 kW	350 kW
Comly	227 kW	2	700 kW	927 kW
Frankford Bus Terminal	375 kW	1	350 kW	725 kW
Victory	325 kW	2	700 kW	1025 kW
Callowhill (satellite)*	-	1	350 kW	350 kW
Southern	300 kW	2	700 kW	1000 kW
Frontier	160 kW	1	350 kW	510 kW
			4550 kW	**6737 kW**

Energy Demands of BEBs

Depot	Existing Connected Load	Number of Fast Chargers @ 450 kW	Number of Slow Chargers @ 180 kW	Additional Connected Load of BEB Chargers	Total Required Connected Load
Midvale	800 kW	2	83	15840 kW	16640 kW
Allegheny	800 kW	2	29	6120 kW	6920 kW
Comly	227 kW	2	35	7200 kW	7427 kW
Frankford Bus Terminal	375 kW	2	30	6300 kW	6675 kW
Victory	325 kW	2	29	6120 kW	6445 kW
Callowhill	375 kW	2	46	9180 kW	9555 kW
Southern	300 kW	2	49	9720 kW	10020 kW
Frontier	160 kW	2	28	5940 kW	6100 kW
				66420 kW	**69782 kW**

SEPTA ZERO EMISSION BUS FACILITY ANALYSIS
ELECTRICAL CAPACITY ANALYSIS
ENERGY DEMAND