CALIFORNIA
ENERGY COMMISSION

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Electric Truck Pantograph Retrofit Project

Prepared for: California Energy Commission

Prepared by: South Coast Air Quality Management District

South Coast AQMD

Gavin Newsom, Governor

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Joe Impulitti, Project officer, South Coast Air Quality Management District
Dr. Michael Lehmann, Siemens AG Deutschland
Primary Authors

South Coast Air Quality Management District
21865 Copley Drive
Diamond Bar, CA 91765
(909) 396-2000
AQMD Website Http://www.aqmd.gov

Contract Number: 600-12-011

Eric Van Winkle
Project Manager

Elizabeth John
Office Manager
ADVANCED FUELS & VEHICLE TECHNOLOGIES OFFICE

Kevin Barker
Deputy Director
FUELS AND TRANSPORTATION

Drew Bohan
Executive Director

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Contributions:

- Dr. Michael Lehmann, Siemens AG Deutschland (coordination)
- Pascal Amar Project Manager, Volvo Group
- Daniel Zimmermann, Project Manager Siemens AG
- Hasso-Georg Grünjes, Head MO TI EH, Siemens AG
- Dave Hart, Project Manager, Siemens Inc.

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program.The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. After receiving approval from the Department of General Services, the Energy Commission issued contract 600-12-011 (January 2014) to initiate the development and demonstration of an electric truck pantograph retrofit system and 600-14-003 (May 2015) an overhead catenary 1-mile test track which facilitated the eventual demonstration of a zero emissions goods movement transportation system.

ABSTRACT

The South Coast Air Quality Management District has identified the development and deployment of zero emissions goods movement transportation systems as one of the agency's top priorities in order to attain federal air quality standards. The San Pedro Bay Ports (ports of Los Angeles and Long Beach) handle about 40 percent of all shipping containers imported to the United States. The containers are off-loaded from the cargo ships to heavy-duty short-haul diesel fueled drayage trucks and then transported along major transportation routes (such as the I-710 corridor) and side roads to nearby industrial warehouse districts and/or railroad yards for eventual distribution of goods throughout California and the United States.

These major transportation corridors and side streets are often surrounded by disadvantaged communities, and the criteria air pollutants emitted by the drayage trucks have a considerable impact on the living environment and health of humans, resulting in respiratory, cardiovascular, and cancer diseases. The freight movement through the ports is expected to increase 30 to 40 percent by 2028 which will only aggravate the negative effects of greenhouse gases and criteria pollutants. This project involved the retrofit of pantographs to three different truck platforms (battery-electric, plug-in hybrid diesel, and plug-in compressed natural gas truck drive-train configurations) and constructed a one-mile long overhead catenary system test track in Carson, California, to test the feasibility of drayage trucks operating as zero-emission vehicles along the major freight corridors/roadways and only engaging their engines when exiting to the various warehouse and railyard areas. Even though the contracts between South Coast Air Quality Management District and the California Energy Commission were directed specifically for pantograph design, build and retrofit (contract 600-12-011 for $1.6M) and construction of the catenary overhead system (contract 600-14-003 for $1.4M), this final report is a comprehensive overall report for the entire $13.5M South Coast Air Quality Management District administered project.

Keywords: pantograph, catenary trucks, eHighway

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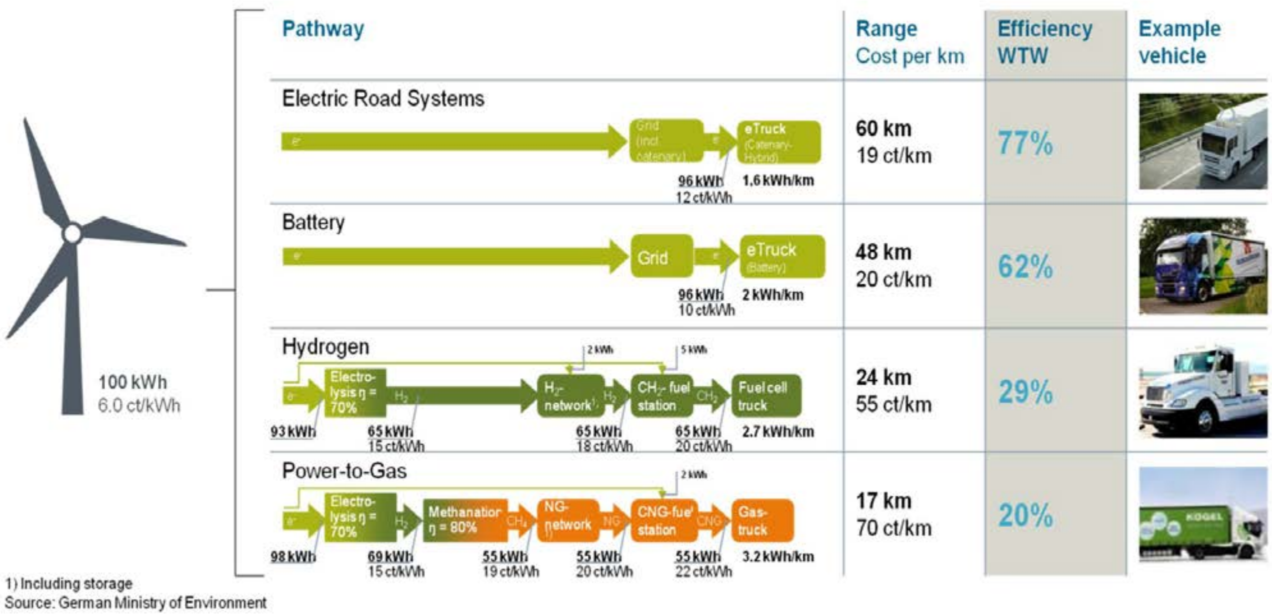
Statement of Project

For heavy-duty vehicles, the diesel engine is used almost exclusively as the method of propulsion. Since the end of the 1960s, it has been possible to reduce the consumption of a 40-ton truck trailer by around a third. By 2030, a further increase in efficiency from 20 to 30 percent is forecasted. While the innovations and the developments for traditional combustion trucks to lower emissions are progressing, the increasing road traffic volume caused by a demanding transport sector is compensating those improvements.

Thus there is the need of a rapid and practicable solution to sustainably lower all emissions - locally harmful exhausts and greenhouse gases. Renewably generated electrical energy will play a significant role in achieving these targets. Taking the increasing demand for renewable electrical energy in all sectors into account will be essential to apply solutions with maximum efficiency. At the same time, the technical and operational limitations of energy storage systems, such as batteries, must be overcome. This can be best achieved by supplying the electrical energy to propel a heavy truck over long distances by means of an electric road system, see Figure 1.

Figure 1: WTW (well to wheel) Efficiencies of Decarbonized Road Freight Options



Source: Siemens AG Deutschland

Electric road systems with external power supply make it possible to upgrade existing road infrastructure and thus avoid the need to develop new costly routes including their long planning and approval procedures. For continuous dynamic power supply, different techniques can be considered (see Figure 38) whereof the catenary type is the most mature. The provision of zero emission corridors based on an electric road system is advisable in order to realize emission reduced transport. Those corridors could provide a major contribution to the targeted emission goals. For sections that are not electrified, the use of complementary technologies, such as batteries, fuel cells, or range extenders with compressed natural gas or synthetic fuels may be added.

The key purpose of the project is to demonstrate the viability of such a zero emission corridor with catenary power supply in combination with a variety of low or zero emission semi-trailer trucks.

Project Objectives

Heavy-duty trucks are the number one source of smog-forming emissions in Southern California. Developing a zero- or near-zero emission goods transport system at the ports will reduce smog-forming, toxic, and greenhouse gas emissions in communities around the ports, which are heavily impacted by air pollution.

The primary goal of this project was to promote the implementation of zero-emission goods movement technologies. The secondary goal was to demonstrate the most viable technology to be adopted for a future, regional zero-emissions corridor. This was done by combining an overhead contact line based electric road system with trucks from different operation equipment manufacturer's suppliers utilizing three different drive technologies.

The key to success and major objectives of the project were the integration of an advanced pantograph into three class-8 trucks to allow full electric operation on the catenary infrastructure built for this project. The catenary system was built in both directions on a 1-mile stretch of Alameda Street in Carson, CA, which is a major truck route heavily used by trucks serving the ports of Long Beach and Los Angeles.

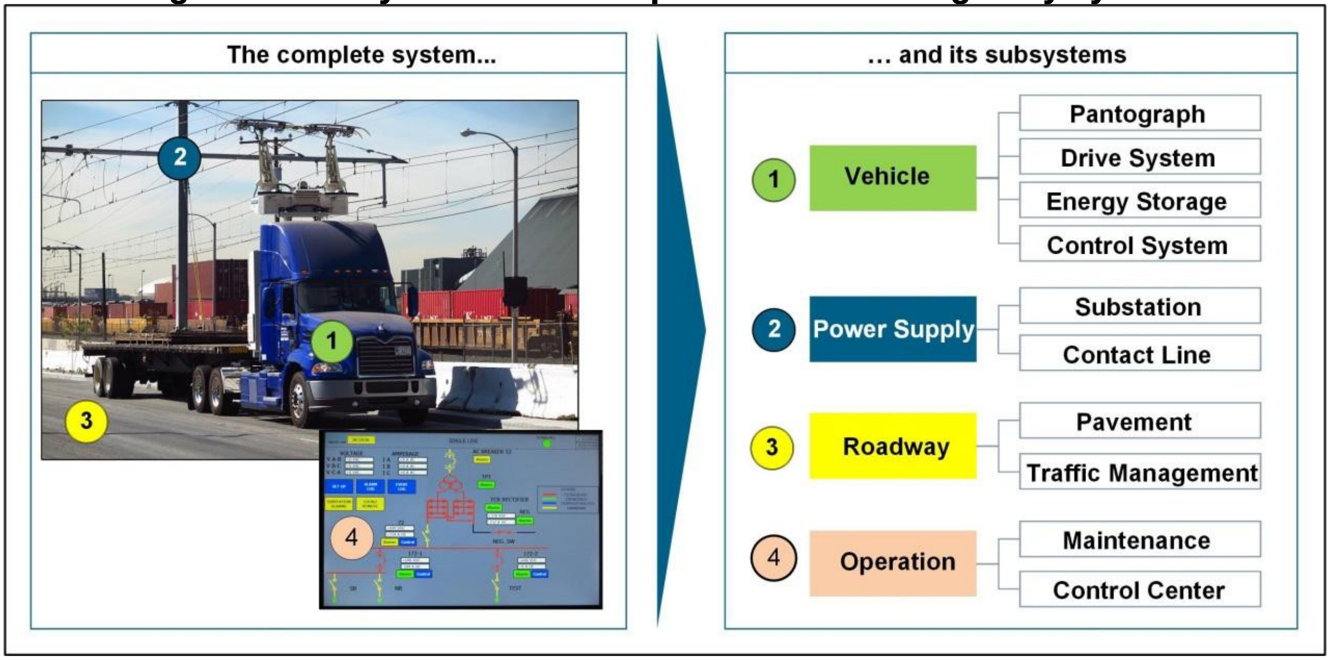
After integration of hybrid drivetrains and pantographs into the trucks, and following the construction of the catenary infrastructure, the project was completed by comprehensive tests under real traffic conditions on a public road. This testing was meant to measure the required parameters, check the operational procedures, and demonstrate the maturity of the solution.

Further objectives of the project are the assessment of the environmental benefits and determination of key financial indicators of the zero emission technology.

The eHighway as a Zero Emission Road Freight Technology

In order to achieve the project objectives, it was necessary to design, build, and commission a catenary infrastructure. This infrastructure consisted of a bipolar, overhead catenary system supported by poles located on the median, a direct current traction power substation, and an operation and control center. Together with the two hybrid and one full electric truck, these subsystems form the eHighway system as shown in Figure 2.

Figure 2: Subsystems and Components of the eHighway System



Source: Siemens AG Deutschland

The road testing of the catenary type zero emission technology required two inter-related work strings. All planning, design, and implementation works of the subsystems with their technical interfaces had to be carried out, including their adaption to the local specifics. However, external stakeholders and technical interfaces, from energy suppliers to road administration, required intense collaboration. Consequently, a major subject and key outcome of the project is an improved understanding of all interfaces that need to be considered for a wider implementation of the technology.

Project Conclusions

The project has shown that the eHighway system can be implemented in an existing road infrastructure as a potential zero emission goods transport technology. During the demonstration, the eHighway system proved to be a viable technology suitable for regional zero-emissions corridors. On the one-mile demonstration track and beyond – depending on the capacity of the onboard energy storage – the class-8 trucks were able to operate without emissions. Based on the demonstration results, the eHighway system can be considered as a valid option for zero emission road freight transports. Provided that renewable electrical energy is used, significant carbon dioxide reductions can be realized.

Implementing the eHighway system requires investments in both road side electrification infrastructure and eHighway adapted trucks. However, such capital expenditure can generate a return on investment as evaluated in the provided business cases. These are influenced by a multitude of factors such as technology costs, efficiency rates, energy pricing, utilization, transport density, and local infrastructure installation conditions. Taking into consideration that the whole concept is still in the research and development phase and has not reached product maturity in all subsystems, the performance of the demonstration on Alameda Street is a very successful proof of concept in a representative application environment. As outlined in chapter

3.3, recommendations for industrialization of the pantograph and the hybrid drive technologies were derived from this milestone project.

Recommendations and Future Work

This project demonstrated that different hybrid drive configurations can be used in combination with the eHighway system. Future work should concentrate on:

- Intensified cooperation with truck operation equipment manufactures to allow for truck and pantograph industrialization. The prototyped hybrid trucks used in the demonstration had inherent limitations such as extended wheelbase and slightly reduced payloads, and therefore are not yet ready to be directly industrialized.
- Further elaboration on the interfaces to energy suppliers with regards to market roles as infrastructure providers and operators (including energy billing).

Since the feasibility of the catenary technology as a highly efficient continuous power supply backbone is demonstrated, and since the eHighway system can be combined with the other technologies for decarbonized zero emission transport, a solid basis for future decisions is provided. Parallel developments in energy storages (for example, batteries) or conversions (for example, fuel cells) will not deteriorate the eHighway concept, but they will increase the overall efficiency on not electrified sections.

Acknowledgment of All Project Sponsors

The eHighway demonstration project was funded by the following parties:

- SCAQMD - Southern California Air Quality Management District
- China Shipping Fund
- California Energy Commission
- Port of Long Beach
- L. A. Metro
- Siemens INC (in-kind contributions)

We as Siemens INC. are deeply grateful for having had the opportunity to demonstrate the viability of this zero emission technology in a challenging public surrounding.

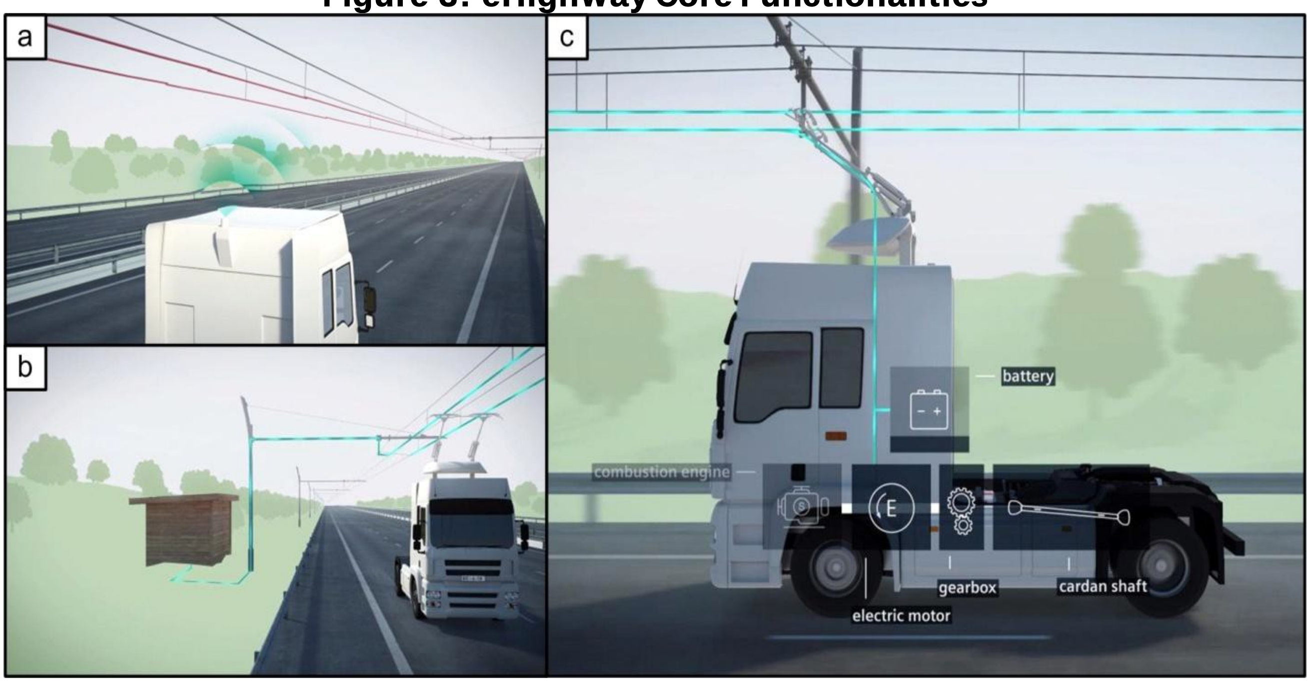
CHAPTER 1:
eHighway – ZE Technology Essentials

To realize the project objectives, it was necessary to design, build, and commission the corresponding infrastructure consisting of a two pole overhead catenary system supported by masts, a traction power substation, and an operation and control center. A second string of work packages was related to the trucks, including their hybridization and the integration of pantographs. While a complete review of the assigned project tasks is given in Chapter 2, this short chapter is meant to provide key information on the technology.

The basic idea of the eHighway technology is depicted in Figure 3:

a) After entering an electrified section, the pantograph equipped truck detects an overhead contact line so that a connection can be established while driving.
b) Once the pantograph is raised and electric contacts in the truck are closed, the external power flow can start via the substation components and the catenary.
c) Within the truck, the electric drive is powered directly from the catenary, and a battery may be charged in parallel for off-line sections.

Figure 3: eHighway Core Functionalities



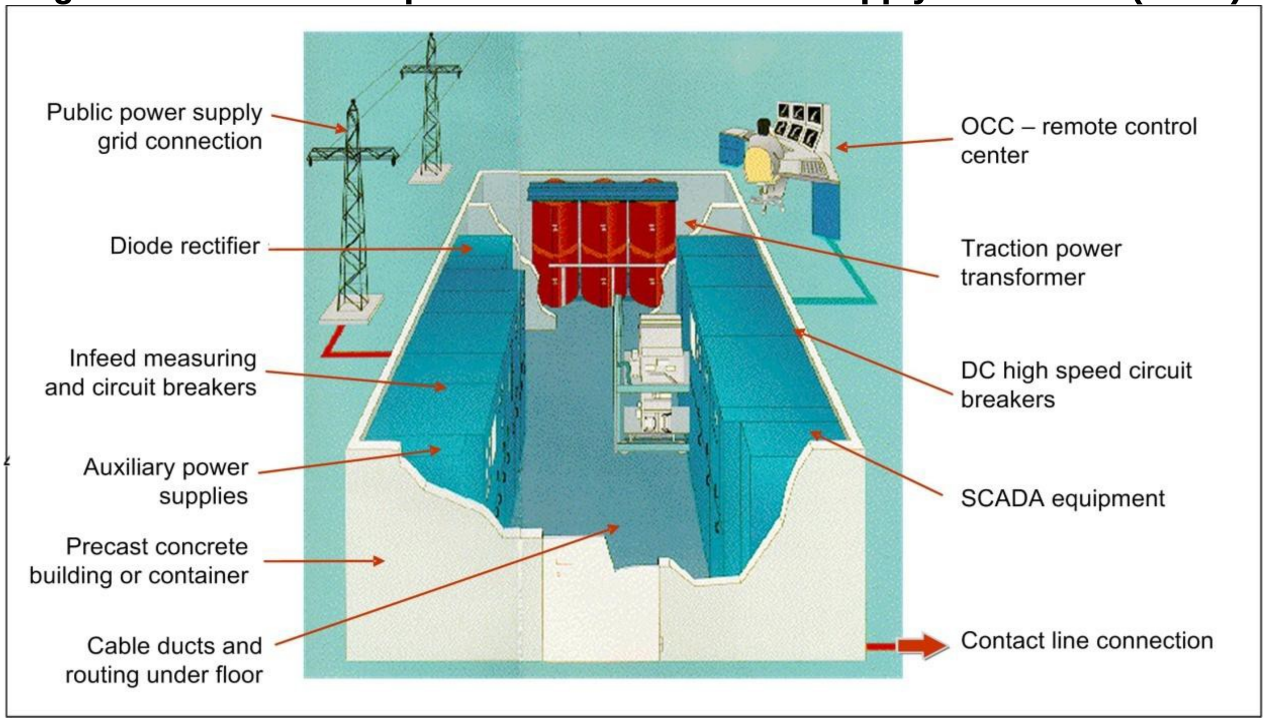
Source: Siemens AG Deutschland

1.1 Substation and Catenary for External Power Supply

The electrical infrastructure system mainly consists of two parts: the substations and the overhead contact line system. Both are based on mature rail electrification technology.

The traction power supply substations have a modular set-up, shown in Figure 4. These substations are designed as containers or precast concrete buildings which are prefabricated and tested at the factory to allow for a fast and relatively simple placement and commissioning on-site. They provide fundamental safety features which, amongst others, allow for safe power turn off in case of any irregularities.

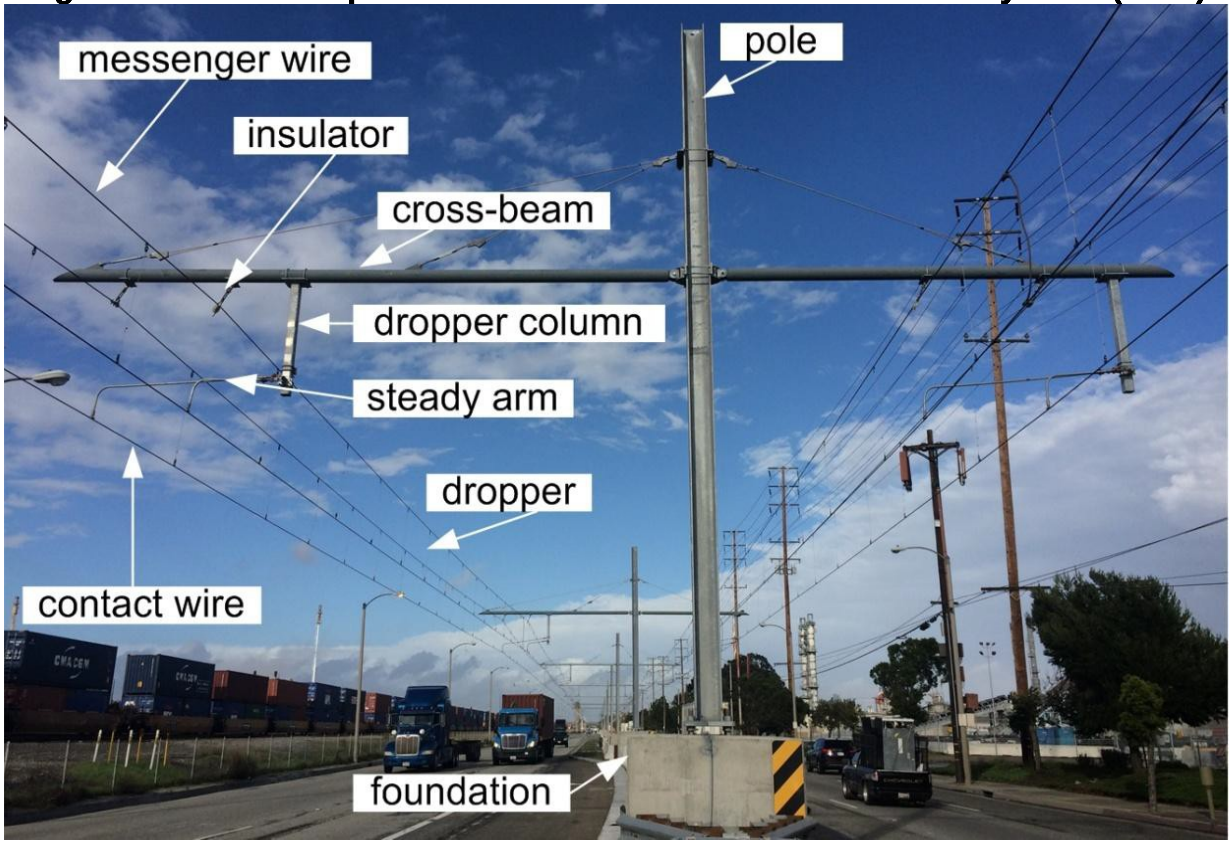
Figure 4: Modular Setup of a DC Traction Power Supply Substation (TPSS)



Source: Siemens AG Deutschland

The overhead contact line system consists of a bi-polar catenary system suspended by cantilever arms which are attached to poles placed alongside the road or on the median. This allows the system to be installed without modifications or interference to the road surface, although crash protection must be individually assessed. The overhead contact line system can be adapted to curves, bridges, and highway entries or exits. The main components of a straight layout are shown in Figure 5.

Figure 5: Main Components of the Overhead Contact Line System (OCS)



Source: Siemens AG Deutschland

1.2 The eHighway Hybrid Trucks and Pantographs

The hybrid configuration of the eHighway adapted trucks allows for contact line interruptions whenever necessary. This may happen when adaptation to the adjacent infrastructure becomes too complex, cost intensive, or the infrastructure is not wanted. The trucks would then disconnect from the catenary wire, proceed on their journey based on their alternative drive system, and reconnect to the catenary system as soon as they reach the next equipped road section. The hybrid trucks for contact line operation consist of two key subsystems - the hybridized or full-electric truck and the pantograph system.

Hybrid Trucks for Catenary Operation

The trucks are based on standard semi-trailer trucks which were modified to enable the utilization of the overhead catenary system. These modifications include adaptations of the drive system and the integration of a pantograph, control system, and energy storage. The test trucks named CCAT and ECAT which were retrofitted and operated by Transposer. The MACK truck was designed, integrated, and operated by Volvo.

Three different drive concepts have been demonstrated in this project:

- CCAT: a serial hybrid with a compressed natural gas (CNG) range extender integrated into a Navistar truck
- ECAT: a full electric configuration with batteries integrated into a Navistar truck
- A parallel hybrid with diesel combustion engine by MACK

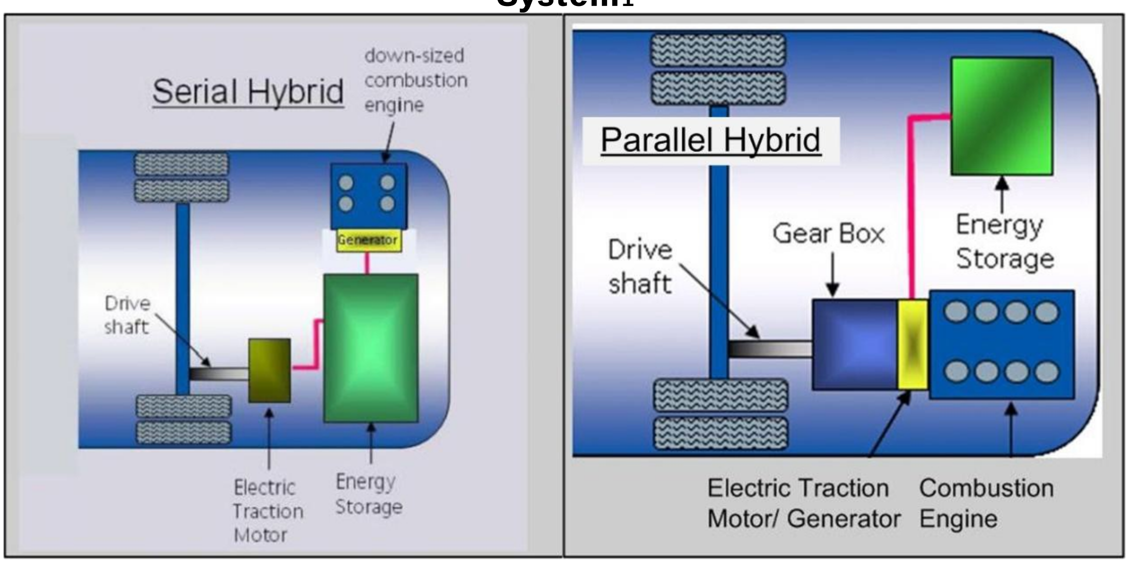
A serial hybrid configuration (see Figure 6, left) is until now most commonly used for heavy duty vehicles, especially in bus applications. The electric engine replaces the manual or automatic transmission of the vehicle, and the combustion motor is connected to a generator. The power is transferred to the drive engines via an electric link (direct current link). The main purpose of the diesel engine is to act as a range extender by loading the onboard energy storage system (battery) while driving without connection to the overhead catenary system. A serial hybrid configuration allows for operating the combustion engine with maximum efficiency within the optimal rotational-speed range. The connection between the electric traction motor and the energy storage (for example, a battery) enables a good recuperation performance when the vehicle is braking. In catenary operation, the power is fed directly to the direct current (DC) link.

In comparison, the parallel hybrid configuration (see Figure 6, right) is more commonly used for heavy duty trucks. The electric engine is integrated into the mechanic transmission (gear box) and drives the axles in parallel to the combustion engine.

Depending on the application, the electric engine and the energy storage is designed for average power in cruising modes to provide higher efficiency in most of the usage time. Nevertheless, the combustion engine must be designed for accelerations and higher power demands. In catenary operation, the power infeed is the link between battery and electric drive.

Besides these two basic principles a number of bridge concepts has been developed that form mixtures between the topologies.

Figure 6: Block Diagrams of a Serial (Left) and Parallel (Right) Hybrid Drive System[1]

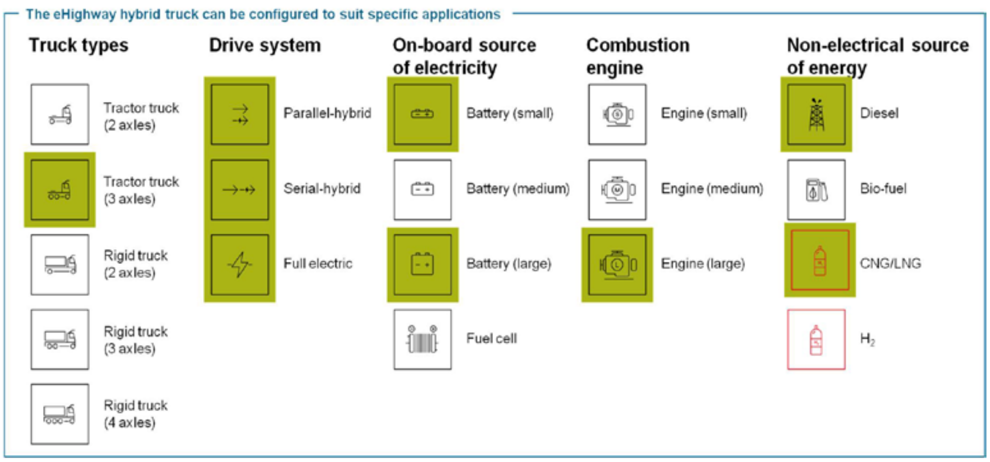


Source: Siemens AG Deutschland

1 *Siemens AG [Hrsg.]:* ENUBA – Elektromobilität bei schweren Nutzfahrzeugen zur Umweltentlastung von Ballungsräumen (FKZ: 16EM0077). Abschlussbericht. München, 2012.

Over the past several years, hybridization has made significant gains even for long- distance trucks. Major truck manufacturers have announced that they will be introducing hybrid vehicles onto the market in the coming years. Figure 7 provides an overview on drive technologies and independent energy supply options for heavy-duty vehicles. The developments in the heavy-duty vehicle sector show that hybridization also represents a decisive component for more sustainable road freight transportation. In a modular hybrid concept, different combinations of drive modules (electric engine or combustion engine) and systems of energy supply or storage (batteries, fuel cells, overhead line, conventional or synthetic fuels) are possible depending on the development status and infrastructure. The applications used in the SoCal project are marked green. The individual vehicle configurations are summarized in chapter 2.8.

Figure 7: Architectures for Catenary Supplied Trucks (green options were realized in project)



Source: Siemens AG Deutschland

Pantograph System

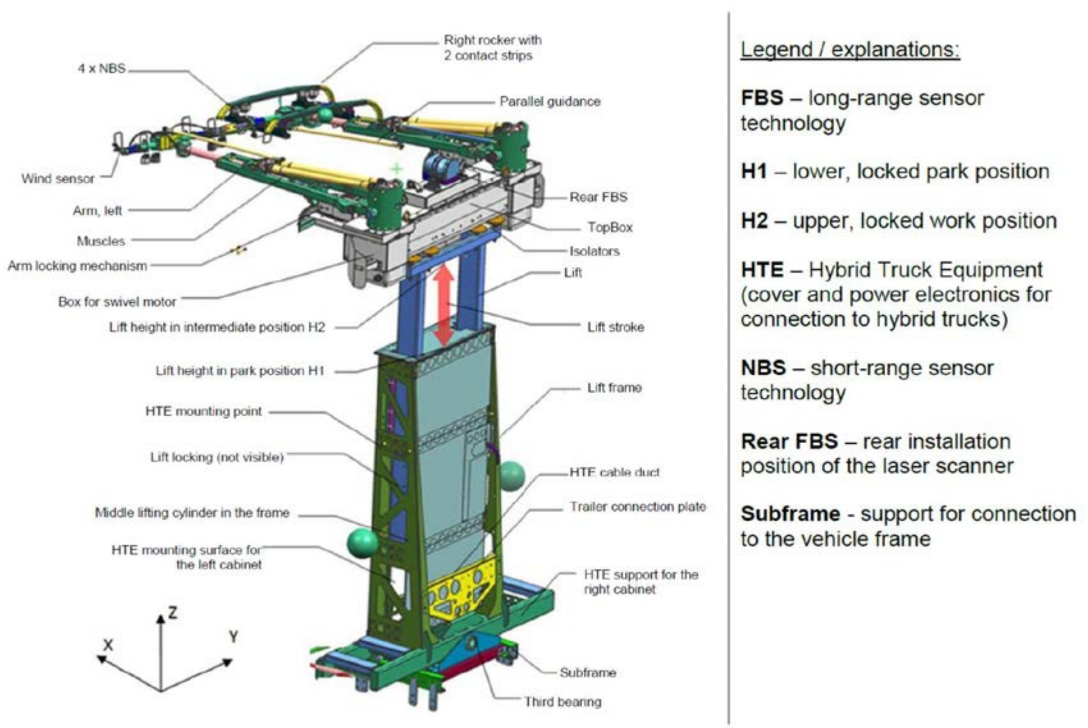
The central innovation of the system is an intelligent pantograph which transfers the electrical energy from the eHighway overhead contact line system to the electric traction motor and the onboard energy storage system. Compared to pantographs used for rail bound vehicles, the eHighway pantograph has to comply with several additional requirements. In railways, the return current can flow back to the substation via the steel wheels and rails. In road applications, the return current cannot flow back via the rubber tires and road surface, so the eHighway system requires a bi-polar overhead contact line system. Because of this, the pantograph has to be able to connect and disconnect with two overhead wires simultaneously. Unlike trolley busses, the connection must be done while driving, as the trucks are not supposed to stop the traffic flow when entering electrified sections.

Road based vehicles are not rail-guided. An active control of the pantograph is required to compensate for the irregular lateral movements of the trucks within their lane. At the same time, a controlled vertical movement of the pantograph has to ensure that the right contact force with the overhead wires is maintained during operation. In order to maintain the flexibility of the trucks and limit their dependence on the overhead contact line system, a safe retraction mechanism is required in case the driver wants to change lanes, overtake other vehicles, or perform an evasive maneuver.

When installed on the truck, the pantograph system may neither limit the loading volume of the truck nor the loading and off-loading operation of goods. Finally, the pantograph system had to be designed so that it can be used by different truck manufacturers and a wide range of truck types.

The basic mechatronic system is shown in Figure 8. Amongst other items, it depicts the connector frame to the base vehicle, the different sensor systems NBS (Near range Sensor, near field) and FBS (Far range Sensor, far field) and the two lift positions. Each pantograph head is comprised of carbon contact strips and four near field sensors to detect out of range use so that a lowering procedure can be triggered.

Figure 8: Mechatronic Concept of Pantograph System Including Main Components



Source: Siemens AG Deutschland

1.3 Roadway

The roadway is formed by the road which usually already exists. Additional provisions have to be considered for a reliable and safe operation of the entire system such as crash protection for poles and substations or additional or modified traffic signs. A traffic management system controls the overall traffic by checking the vehicle density and supervising the individual lanes in case of maintenance works.

Special care must be taken for existing roadside installations such as traffic lights, overhead road signs, and bridges. Depending on the specific situation, additional insulation layers, protective elements, or adjustments of the existing infrastructure need to be designed and installed.

1.4 Operation and Maintenance

Similar to a rail electrification system, the eHighway system has an operation and control center (OCC). The status of the road electrification infrastructure can be monitored and modified via a SCADA (Supervisory Control and Data Acquisition) system. From within the OCC, it is possible to de-energize specific sections in order to allow for maintenance work. The collection of data from the power substations or trucks operating in the relevant area is beneficial to gain a high availability of the entire system. Additional functions may be the collection of pantograph status information to determine correct system properties or initiate maintenance activities. Further tasks of an OCC or a control center at a higher level may be the measuring and billing of the energy used. This function is optional and depends on the operational model used.

CHAPTER 2: Scope of Work

The overall scope of the project is comprised of the development and demonstration of an overhead catenary system (infrastructure) and corresponding pantograph's ability to power various operation equipment manufacturers (OEM) class 8 trucks with different hybrid propulsion systems.

The interfaces of the pantographs to the trucks were to be defined by Siemens. Further work items included the testing and commissioning of the pantographs at the truck manufacturing and laboratory sites. In total, four adaptable pantograph systems were manufactured to be installed and integrated on the trucks.

The bipolar DC catenary system was designed and installed in both directions along Alameda Street. The approximate one-mile segment extends north to south from E. Lomita Blvd to the Dominguez Channel. In the middle, underneath Sepulveda Blvd. overpass, a containerized traction power rectifying substation and a control center had to be installed.

The project was to be include a 12-month testing and demonstration phase, but due to construction delays, it was agreed to be reduced to 6-month demonstration. This reduction was necessary since the operational license could not be extended.

The project was split into twelve individual tasks as listed in Table 1. It reflects the contractual requirements and sequence of the tasks according to the statement of work.

As all tasks were to be reported in detail with individual deliverables, this final project report concentrates on brief summaries of the individual tasks in the following sub-chapters.

Table 1: Project Tasks and Assignment of Report Chapters

Title	Chapter
Basic Infrastructure System Design	2.1
CEQA and Construction Permitting	2.2
Infrastructure System Detailed Design	2.3
Procurement and Manufacturing - Infrastructure	2.4
Installation and Commissioning of Infrastructure	2.5
Pantograph System Definition and Interface Identification	2.6
Pantograph Engineering Integration and Certification	2.7
Pantograph Production, Assembly and Integration into Each Vehicle	2.8
Catenary Truck and Infrastructure Demonstration	2.9
Determine Owner and Operator of System	2.10
Project Management and Reporting	2.13
System Decommissioning and Site Restoration	2.14

Source: Siemens AG Deutschland

2.1 Basic Infrastructure System Design

Task 1 - Basic Infrastructure System Design comprised a package of engineering and planning documents mainly to illustrate and outline how the stationary infrastructure was planned to be realized. The documents served as a basis for detailed engineering and the application and approval for construction and operational permits.

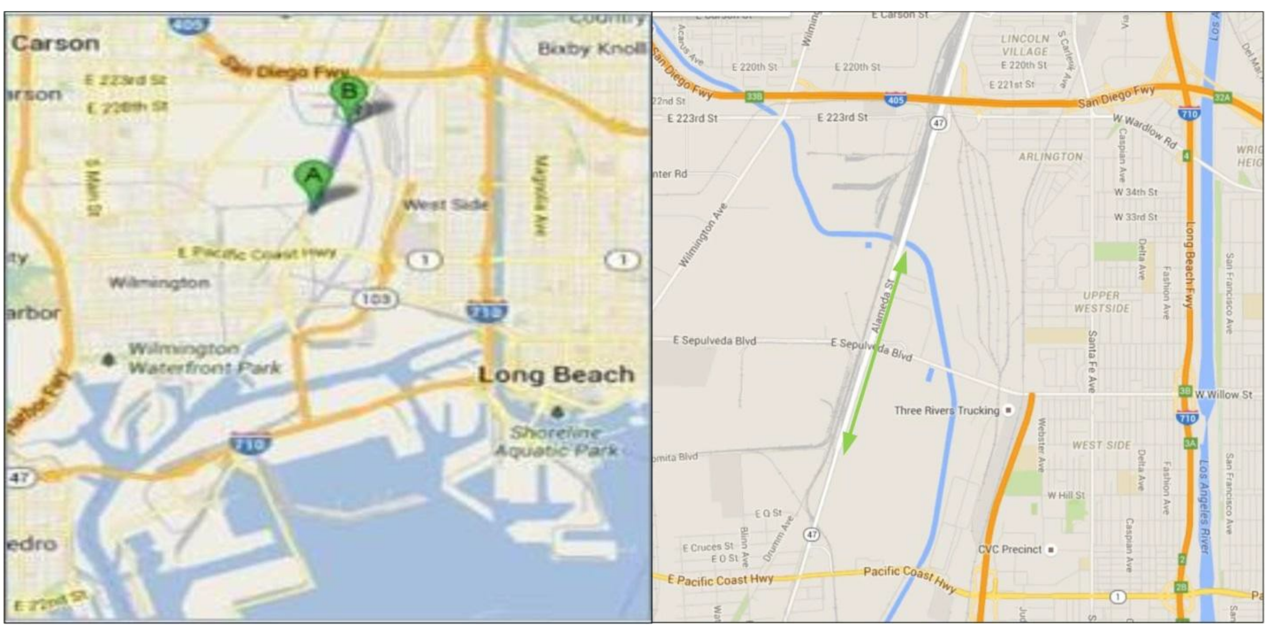
The submission of this package included the following documents:

- site evaluation and report
- single line diagram of the substation
- layout plan of the overhead contact line
- building layout and a site power and signals cabling plan

Other than the site evaluation report, all other documents were updated and summarized in two documents that can be found under Task 3 - Infrastructure System Detailed Design (see chapter 2.3).

For the erection of the catenary infrastructure, a section of CA Highway 47 named Alameda Street was chosen. It is a truck route running parallel to Interstate 710 and Terminal Island Freeway. These truck routes connect the harbors of Long Beach and Los Angeles to a number of inland cargo distribution and container handling facilities. The chosen section of Alameda Street belongs to the city of Carson, CA. Figure 9 shows the localization of the chosen section in large scale and in a street map.

Figure 9: Localization of the eHighway Site in Carson, CA



Source: Siemens AG Deutschland

Visual impressions of the site prior to infrastructure construction are given in Figure 10. The images a and c were taken looking southbound, the images b and d looking northbound.

The section south of Sepulveda Boulevard overpass was characterized by a very small median strip and no sidewalks as it directly neighbors a railway yard and a fuel depot. For the section north of Sepulveda Blvd. overpass, a number of left-turn lanes and varying median widths and layouts are characteristic.

In order to simplify construction of the overhead contact line system, the installation of the poles on the median between the northbound and southbound roadway was a project prerequisite by the customer and carried out accordingly.

Figure 10: Alameda Street at Carson, CA with the Chosen Section for Infrastructure Construction

Source: Siemens AG Deutschland

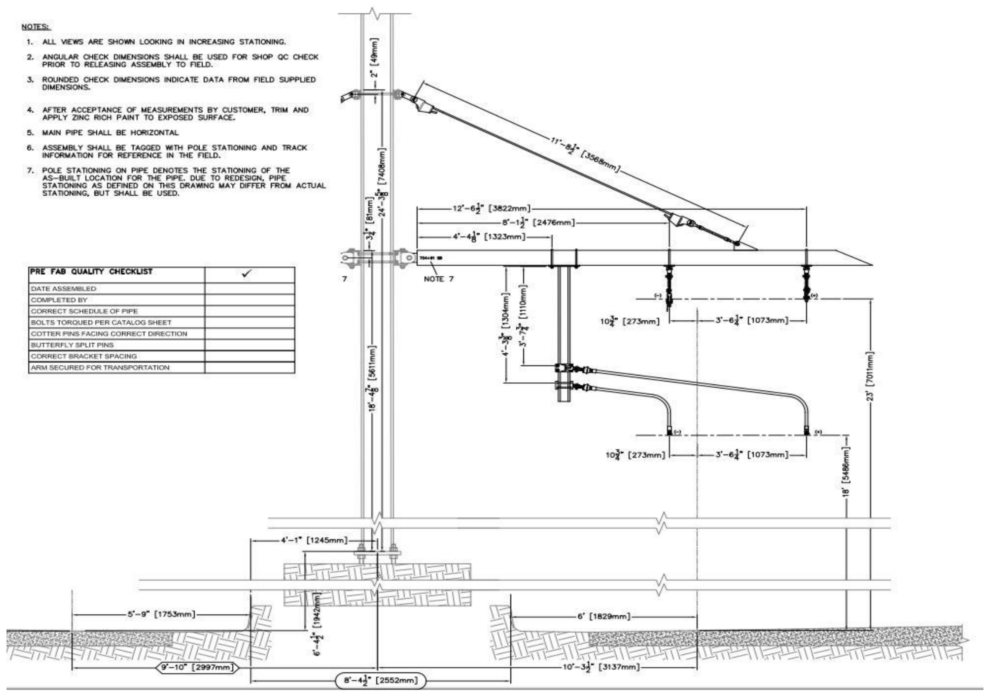
2.2 CEQA and Construction Permitting

A CEQA (California Environmental Quality Act) self-assessment for the application of the construction permission was prepared. Furthermore, the following documents were submitted to the city of Carson to complete the application.

- Cover and Vicinity Map
- General Symbols and Abbreviations; Legend and Symbols Sheet
- Structural General Notes
- Civil Plans, Plan and Profile
- Maintenance Facilities and Test Track
- Civil Plans Sections and Details
- Overhead Contact System – Assembly, Foundation and conduit mounting
- Building Structural Plans, such as TPSS Foundation
- Low Voltage Single Line Diagram
- Power and Signals Overall Site Plan
- Grounding Plan and Details

Based on the application and documents submitted, a permit was issued by the City of Carson which granted the installation and construction activities of the catenary system. During the early construction phase that started with the drilling of the originally planned steel pipe foundations, an unexpected additional underground facility (a pressurized gas line) was found. This led to a complete redesign and re-permitting of all pole foundations to an above ground precast gravity concrete foundation, shown in Figure 11. The above ground pole foundations necessitated a traffic abutment system in the median, as well as various traffic safety systems such as crash attenuators and guard rails.

Figure 11: Cross Section of a Standard Pole with Precast Concrete Foundation



Source: Siemens AG Deutschland

2.3 Infrastructure System Detailed Design

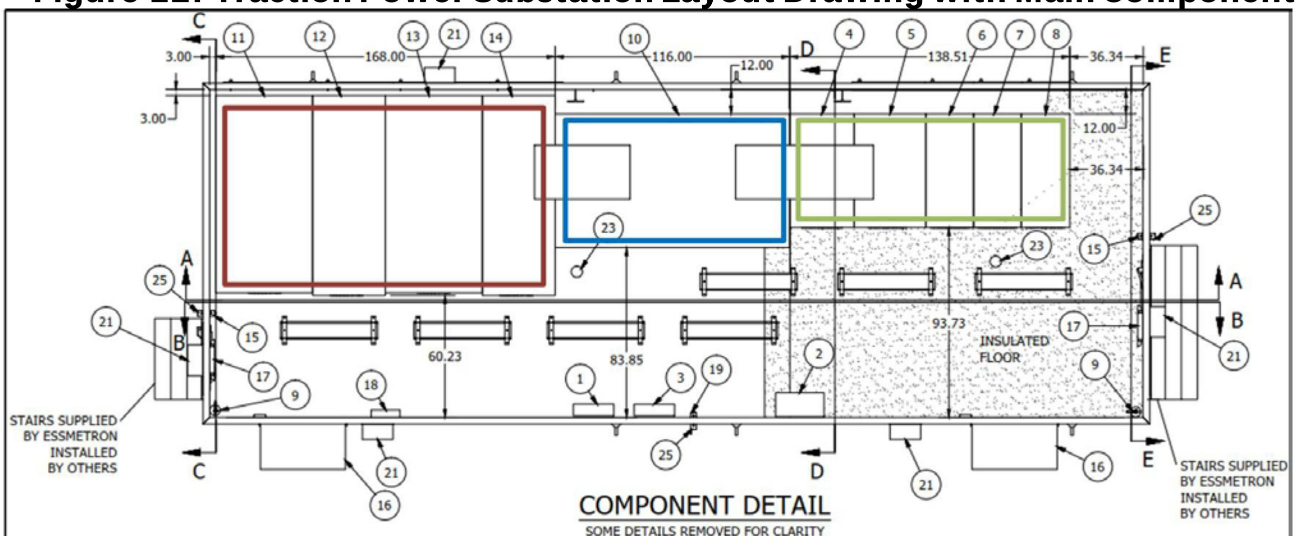
Task 3 was focused on the detailed design of the infrastructure system and comprised following sub-tasks:

- Detailed design of the traction power supply station
- Detailed design of the overhead contact line system
- Description of the test procedures

Traction Power Supply Station TPSS (Substation)

The design is based on standard components for electrical railways and tramways. For the planned operation of a maximum of four trucks, the rating of the power transformer was set to 1 MVA with a correspondent 12-pulse-diode rectifier. The operating voltages are 3~AC 12 kV medium voltage for the infeed and DC 600 V nominal traction voltage for the OCL to feed the trucks. The substation auxiliary supplies run at AC 120 V. An overview of the substation layout and the main components is shown in Figure 12.

Figure 12: Traction Power Substation Layout Drawing with Main Components



Traction components:	**4-8 DC traction power section (rectifier and switchgears)**
	10 (main) power transformer
	11-14 AC medium voltage section (switchgears and measuring)
Secondary equipment:	1-3, 9, 15-25 auxiliaries including lighting, outlets, ventilation, doors, switches

Source: Siemens AG Deutschland

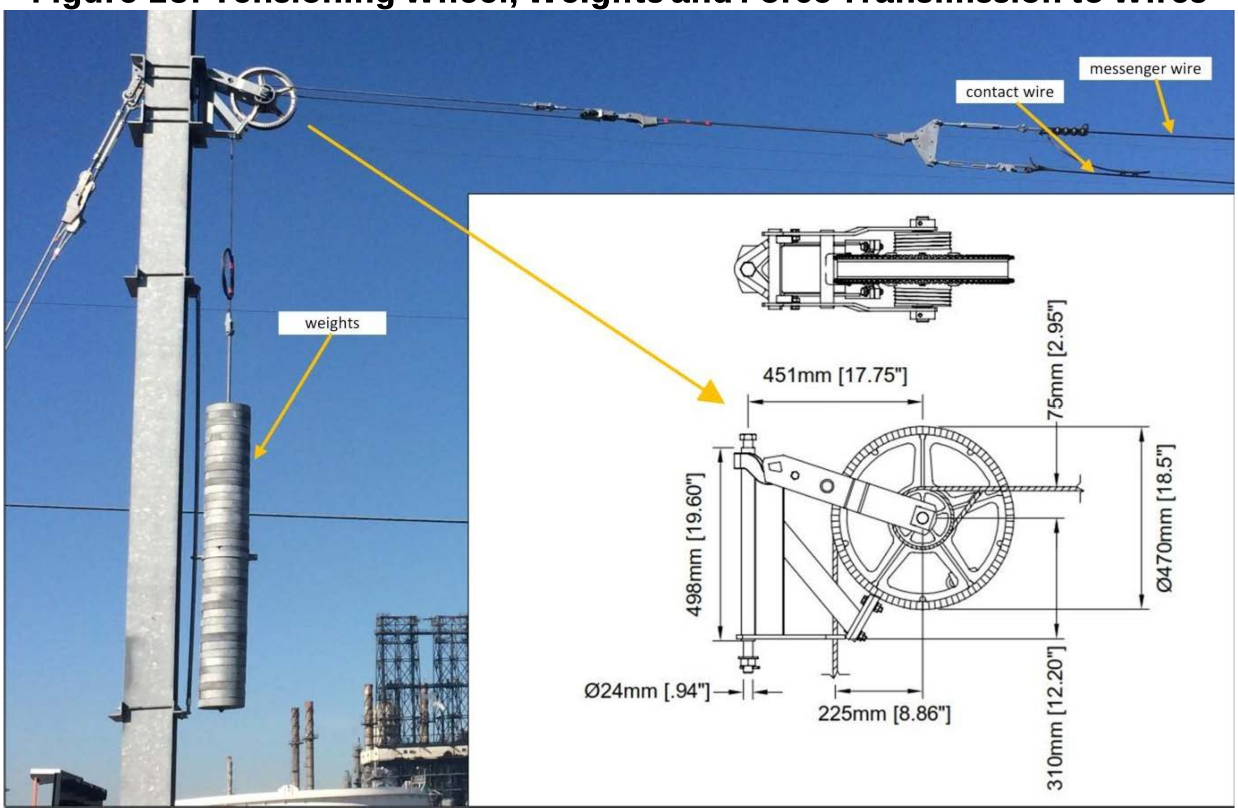
Overhead Contact Line System (OCS)

As part of this sub task, an updated site plan was provided. Further documents included details about installation methodology and standards which have to be considered for materials and processing. The engineering submission also contained parts lists and drawings lists for the poles and the catenary. The overhead contact line system consists of catenary type contact lines for both electric poles and for both directions. Each catenary consists of a steel rope messenger wire with a cross section of 70 mm² that support a copper magnesia alloy as contact wire with a cross-section of 150 mm². The choice of the conductors is subject of a power flow study considering variables like traffic assumptions, power demand, substation spacing.

The catenaries of the poles a laterally spaced at 1.35 m (53'') at a nominal height of 5.48 m (18 ft) above ground. A cross-section is shown in Figure 11.

The contact and messenger wire are tensioned with concrete weights via suspension wheels that are located at beginning and end of the electrified section. The tension wheels serve to keep a continuous tensile strength within the conductors while mitigating the thermal length deviations according to varying outside temperatures. A typical assembly is shown in Figure 13.

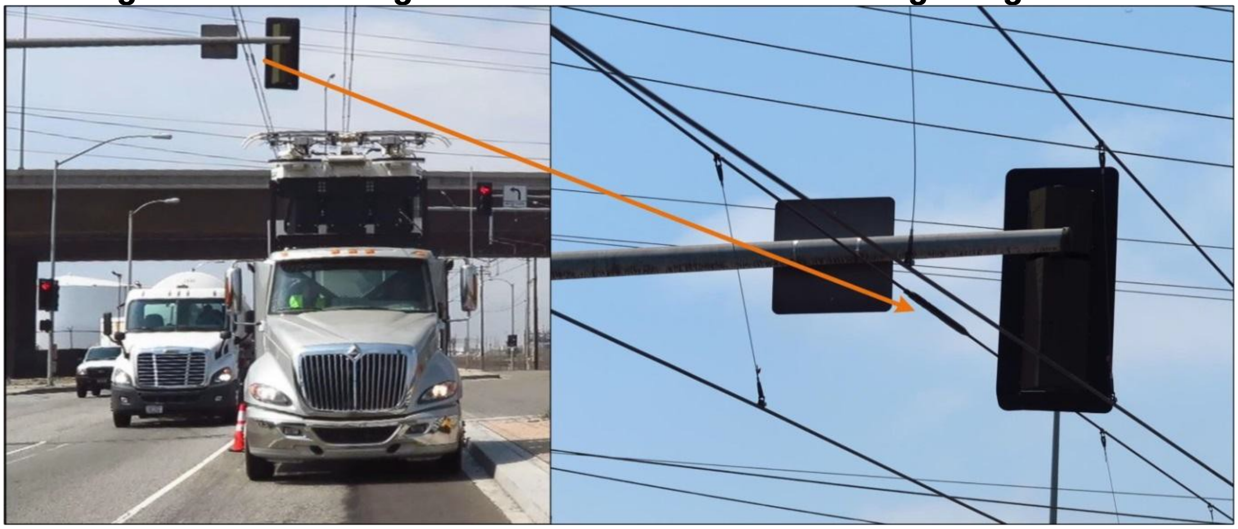
Figure 13: Tensioning Wheel, Weights and Force Transmission to Wires



Source: Siemens AG Deutschland

As a road specific adaption, one of the messenger wires had to be insulated because it could possibly get too close to the existing traffic light signal unit. Figure 14 shows that detail.

Figure 14: Messenger Wire Insulation at Traffic Light Signal Unit



Source: Siemens AG Deutschland

Infrastructure Test Procedures and Descriptions

Tests are crucial for the proper and reliable functionality of a system. For this sub-task, test procedures were submitted that were also used to perform testing of the project infrastructure. This includes the traction power substation, the overhead contact line, and the general site. The comprehensive collection of test procedures includes production (factory) testing, field testing, and commissioning as applicable to this subsystem.

A test matrix excel sheet was attached. The matrix described which test procedures are for production, field, or commissioning tests. Although all test procedures were submitted under Task 3, the performance of the individual tests was part of later tasks.

2.4 Procurement and Manufacturing – Infrastructure

The test descriptions introduced in the previous section form the basis for the requirements of Task 4. It is separated in three different subtasks comprising factory acceptance tests (FAT) for the traction power supply station (TPSS), the overhead contact line systems (OCS), and the auxiliary infrastructure.

Traction Power Supply Station TPSS (Substation)

Comprehensive technical and functional tests of the AC high voltage cabinets and the DC units were conducted for the TPS including:

- DC breaker truck production test
- DC incoming/feeder cubicle production test
- Negative cubicle production test
- Rectifier production test
- TPSS field test (same procedure as used for field commissioning)
- AC switchgear production test

The DC Feeder breaker functional tests included preliminary settings and functionality checks of the protection relays. The most important functions tested were:

- Maximum current tripping
- Relative current rise function
- Absolute current step function
- Transformer temperature warning and tripping
- Maximum and minimum voltage tripping

For the transformer, a separate FAT was issued by the manufacturer Schaffner MTC Transformers. Figure 15 displays an excerpt of the FAT protocol where the different losses for magnetization caused by the current flow in the winding systems under load were measured. Over a wide load range, the transformer efficiency is at about 98.8 percent, so even moderate loads do not cause increased losses. The transformer has one primary high-voltage winding system and two secondary winding systems using a star-delta configuration to reduce harmonic distortion in combination with the 12 pulse diode rectifier. A detailed analysis of the grid impact was done by Southern California Edison (SCE) that proved no negative effects of the eHighway power supply[2].

Figure 15: Main Transformer Efficiency as Confirmed in FAT (Factory Acceptance Test)

		% LOAD	% Eff
Core Loss	3000	125%	98.72%
Load Loss	9049	100%	98.88%
Total Losses	12049.4	75%	98.99%
		50%	99.02%
		25%	98.67%

Source: Siemens AG Deutschland

All tests for all substation components were passed without any objections. After the FAT the TPSS was ready for the shipment to the construction site at Carson, CA.

Overhead Contact Line System (OCS)

This subtask comprised a documentation of testing results as applicable for production requirements of each product supplied by Siemens for the OCL or purchased by vendors. The production tests have been conducted in the Tualatin, OR warehouse (unless stated otherwise on the test reports) and followed Siemens quality guidelines. The tests required for release to construction site depend on the properties of each product and were defined and implemented to provide a consistent quality of goods.

[2] *SCE - Southern California Edison:* Grid Technology and Modernization File, eHighway Grid Impact Assessment. Memorandum by Ioan, A. and Smith, J. Record No.: TC-15-027-TR06. Pomona, CA, February 2018. (internal report)

For the different parts and groups, the following tests are applicable:

- Fittings and hardware (visual and dimensional tests; sample galvanizing)
- Insulators:
    - Visual and dimensional tests
    - Dielectric insulation test
    - Mechanical load proof test, see Figure 16
- Wires:
    - Visual and dimensional tests
    - Mechanical tension and elongation tests
    - Electrical resistance test
    - Twist test
- Poles (Certified material test, welder certificate)

Figure 16: Mechanical Load Proof Test for Cast Resin (Above) and Silicon insulators (Below)

Source: Siemens AG Deutschland

Auxiliary Infrastructure

An FAT was done for the temporary office for site and control room. Other facilities such as CCTV, fences, etc. were tested under Task 5.4 auxiliary infrastructure field acceptance test report.

2.5 Installation and Commissioning of Infrastructure

All site installation works were finalized with extensive tests to prove the reliability and safety of all components and subsystems. They were conducted by qualified personal, witnessed and documented.

Overhead Contact Line System (OCS)

For the OCS, a mechanical acceptance test was done comprising of foundations of the poles, cantilevers and head spans, contact wires and droppers, messenger wires, insulators, and pole mounted disconnectors. The disconnector was tested electrically. The test was successful and minor irregularities could be fixed on short notice.

The tests included:

- OCS Electrical test, including high potential and isolation testing
- OCS Energization test
- OCS Mechanical Inspection, including height control

Traction Power Supply Station TPSS (Substation)

This test is to prove that all of the connections are correct and that no shipping damage has occurred to the insulators or other components. Since those tests are an important safety feature for the entire system they were quite comprehensive and took several days. Beside visual inspections, measurements, functional tests, and readjustments to the settings were done.

- TPSS Field function test
- TPSS Energization test
- TPSS Short circuit test
- AC Main breaker Siprotec relay settings
- Transformer temperature monitor settings
- DC Positive switch settings
- DC Feeder breaker Sitras Pro relay settings

After these tests were completed for both subsystems the eHighway demo track was ready to start the system integration with the modified hybrid trucks along the Alameda Street.

The pictures on the following two pages illustrate the construction process:

- Figure 17 a – delivery and positioning of precast concrete foundations
- Figure 17 b – all concrete foundations placed, median widening completed
- Figure 17 c – all poles placed, begin of route with crash attenuators
- Figure 17 d – all poles placed, northbound view from intersection
- Figure 18 a – preparation of the TPSS site
- Figure 18 b – delivery of the TPSS and unloading by crane
- Figure 18 c – catenary works with fork lifts
- Figure 18 d – catenary works with fork lifts

Figure 17: Construction Phase – Setting of Foundations and Poles

Source: Siemens AG Deutschland

Figure 18: Construction Phase – Substation (TPSS) and Catenary Works (OCS)

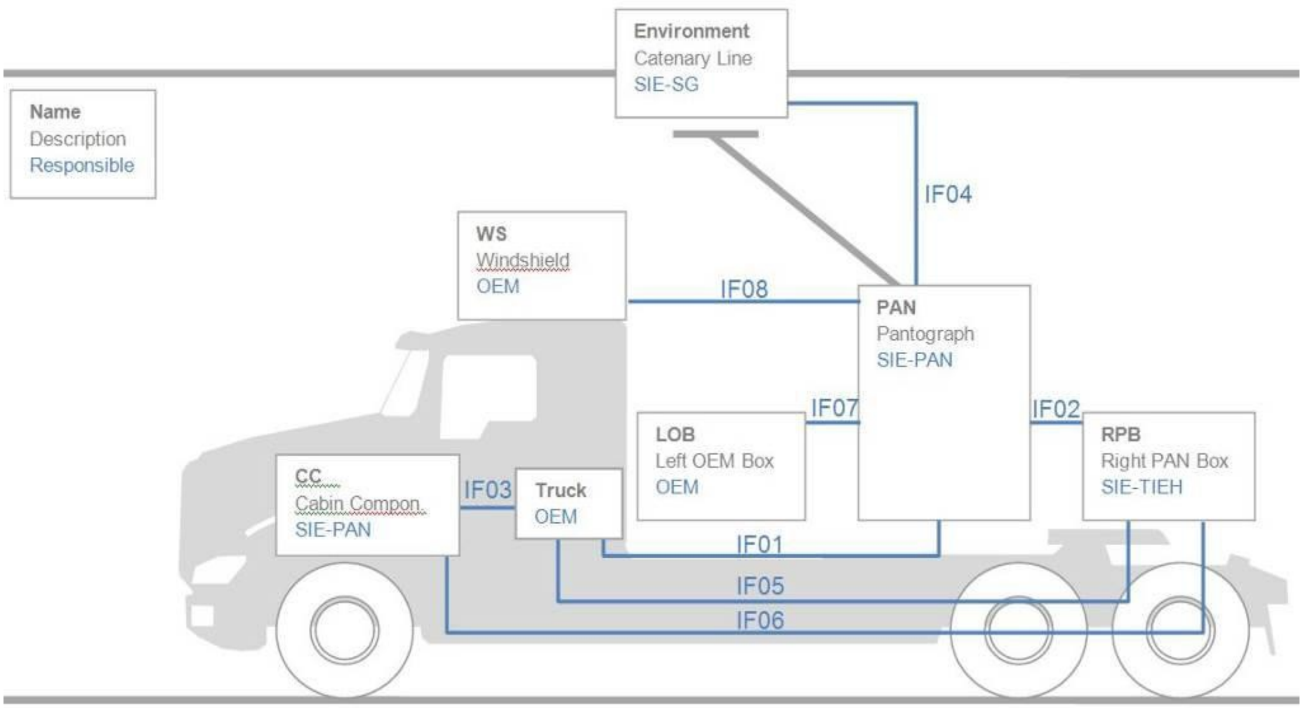
Source: Siemens AG Deutschland

2.6 Pantograph System Definition and Interface Identification

During the design process for the different hybrid trucks, a comprehensive interface synchronization between the Siemens pantograph system and the different OEMs and integrators was necessary. For identification and definition, the interfaces were structured in different categories based on developments over several years. This structure was also used as a basis for the integration tests at the OEMs test sites. Moreover, this structure is transferrable to other hybrid trucks and helps to standardize and optimize pantograph integration as individually customized solutions are limited.

All interfaces were successfully implemented during the project together with the OEM partners Volvo and Transpower. Figure 19 gives an overview about the interfaces followed by a brief characterization of the interface contents.

Figure 19: Pantograph Interface Overview



Source: Siemens AG Deutschland

IF01 – Mechanical interface: PAN – Truck

This interface defines the mechanical interaction between the truck and the pantograph. Dimensions, weight, and speeds are settled in this interface. The mechanical mounting to the base frame with an adaptable sub-frame is the responsibility of the truck supplier.

IF02 – Right PAN Box – Pantograph

The right PAN box contains all electrical and pneumatic elements to control the pantograph. It serves also as main interface enclosure for signals, electrical power, and pneumatics necessary to control the pantograph.

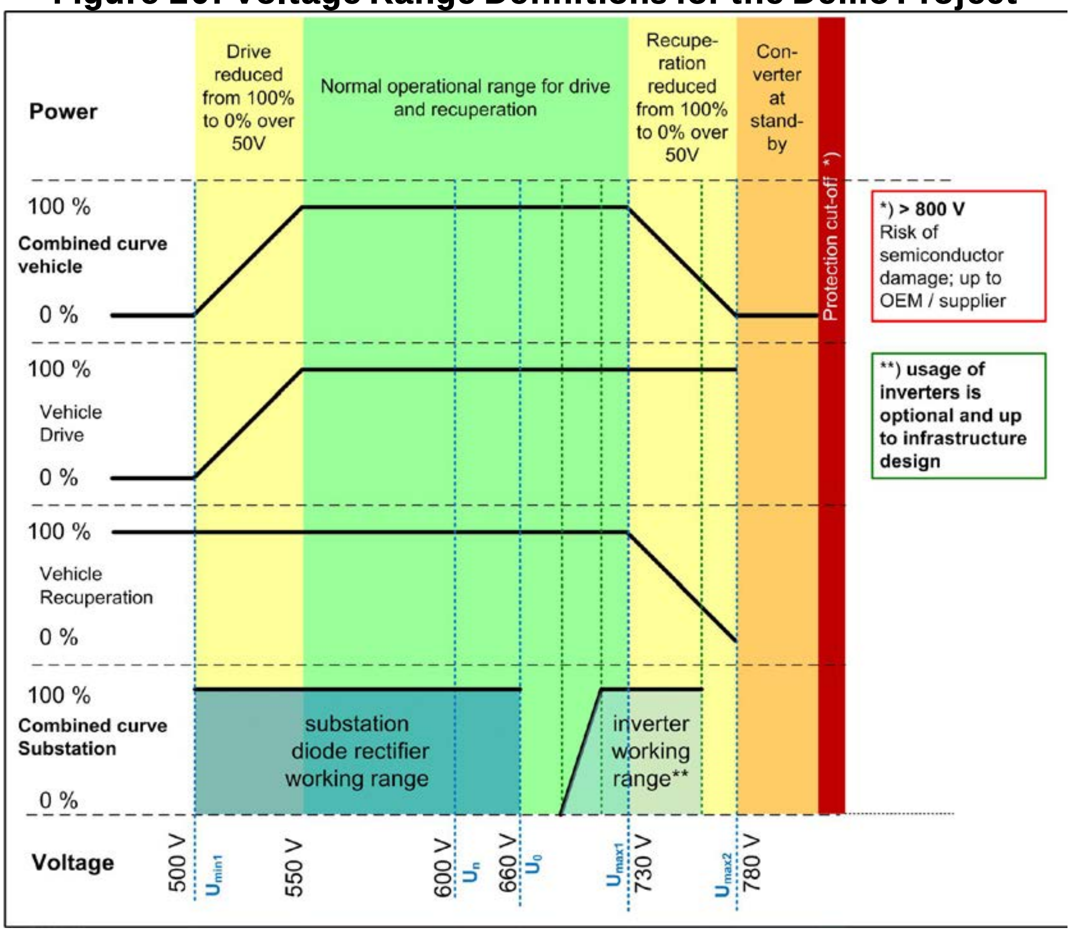
IF03 – Truck – Cabin Components

For the communication between the truck cabin and pantograph, a touch screen and additional dashboard buttons are installed as human machine interface (HMI). This interface defines communication with the CAN-Bus of the truck and contains message definitions.

IF04 – SIE-SG – OEM

This interface outlines the electrical parameters for the power consumption of the electrical drive system. It defines performance ranges the power supply, the pantograph, and the electric hybrid drive are designed for. The voltage range definitions used for the EHWY SoCal project were according to Figure 20. For the demo project on Alameda Street no inverter was installed at the substation.

Figure 20: Voltage Range Definitions for the Demo Project



Source: Siemens AG Deutschland

IF05 – Truck – Right PAN Box

This interface defines the pneumatic and electrical requirements between the truck and the pantograph. Cables and hoses are determined and responsible for the supply of all media including control signals, pressurized air, pantograph drive and main cabling for current transfer to truck drive.

IF06 – Right PAN Box – Cabin Components

This interface defines the signal characteristic requirements for the communication between the truck and the right PAN box via communication busses of Ethernet or Profinet type.

IF07 – Truck – Left OEM Box

The left OEM box provides an installation space for interface components of the OEM truck. Mechanical data and dimensions are defined in this interface.

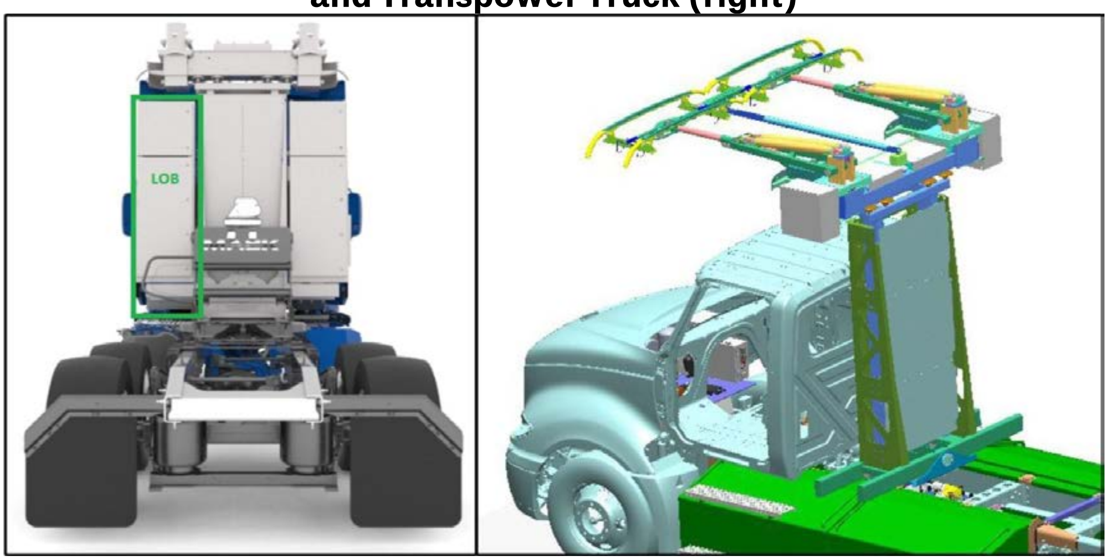
IF08 – PAN – Windshield

This interface defines the mechanical space requirements for a windshield which is part of the truck equipment and can be mounted on the cabin to reduce aerodynamic drag. A 3-D model was provided to the truck manufacturer considering the needed ranges for movements of the pantograph.

2.7 Pantograph Engineering Integration and Certification

There were in total four pantographs manufactured and tested at the workshops. After the pantographs left the assembly line they were tested and certified in a dedicated test field, see Figure 22. All four pantographs had the same technical design but were fabricated in sequence. In parallel, the integration planning into the individual trucks started. 3D-Models were used for the mechanical integration, as shown in Figure 21 for Volvo[3] and Transpower trucks[4].

Figure 21: 3D-Model of Pantograph Integration Into Volvo (left) and Transpower Truck (right)



Source: Siemens AG Deutschland

3 *Volvo Group:* Demonstration of Siemens Electric Road System on Diesel Electric Hybrid Truck - eHighway Vehicle Test Report. Report by Amar, P. and Larsson, B. Record No.: P4348. Gothenburg, January 2018. (internal report)

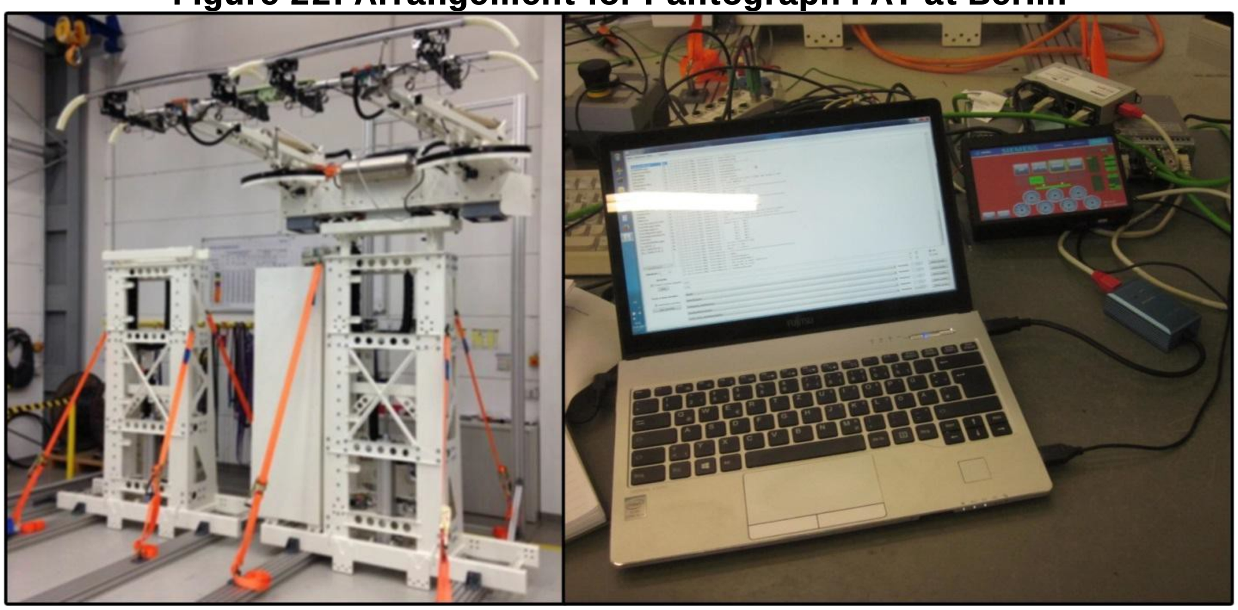
4 *TransPower:* Electric and CNG Hybrid Trucks for the Zero Emission Truck & Electric Catenary Highway (ECHT-ZETECH). Final Report. Escondido, CA, December 2017. (internal report)

The FATs were performed individually at the manufacturing site in Berlin. For the FATs, the pantographs were connected to the operation panel (HMI) in order to be installed in the truck cabin later on (see Figure 22). The right PAN box containing several control elements for the pantograph was pre-tested in the assembly factory in Chemnitz/Germany. The FAT configuration consists of the pantograph system, including an external compressed air supply, external DC 600 V power supply, and the cabin components with related software licenses. Open issues were listed at the end of the FAT report.

In particular, the following tests were conducted:

- Visual Inspection:
  - Pantograph arms
  - Topbox lift
  - Right PAN box
- Functional Tests:
  - Startup and shutdown
  - Operational functions
  - Safety functions including automated dropping device (ADD) to detect broken carbon contact strips
  - Graphical user interface, operating messages

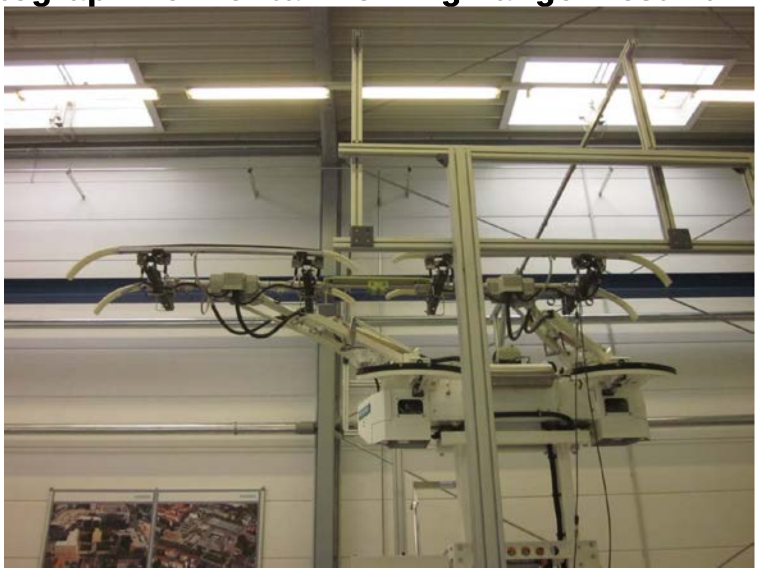
Figure 22: Arrangement for Pantograph FAT at Berlin



Source: Siemens AG Deutschland

A key test refers to the pantograph control and lateral working range. Figure 23 shows this test with the ultimate horizontal arm positions. Proper functionality of the lateral arm movement was a pre-requisite for the planned tests with trucks operating at the edge of lane to determine usability over the full lane width.

Figure 23: Pantograph Horizontal Working Range West During FAT at Berlin

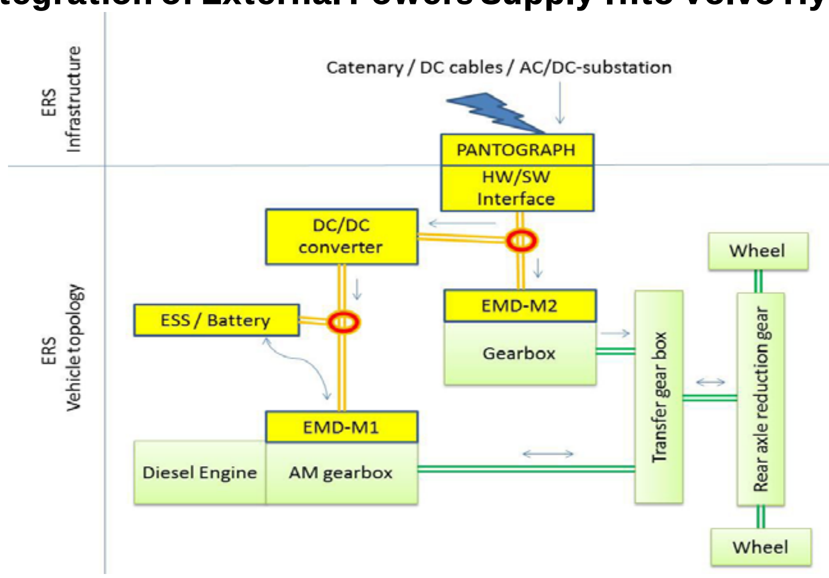


Source: Siemens AG Deutschland

2.8 Pantograph Production, Assembly and Integration into the Hybrid Trucks

After manufacturing, the pantographs were packed and sent to Poway, CA (Transpower facility) and to Gothenburg (Volvo plant). The pantographs were integrated into the trucks at these plants. Figure 24 shows the hybrid drive topology of Volvo and their pantograph - driveline interface. Integration was completed with further interface tests and ultimately with a site acceptance test.

Figure 24: Integration of External Powers Supply Into Volvo Hybrid Driveline[5]



Source: Siemens AG Deutschland

5 *Volvo Group:* Demonstration of Siemens Electric Road System on Diesel Electric Hybrid Truck - eHighway Vehicle Test Report. Report by Amar, P. and Larsson, B. Record No.: P4348. Gothenburg, January 2018. (internal report)

The final integration tests were performed at the test track on the Alameda Street for the Transpower trucks. The tests were comprised of checks of mechanical and electrical functions as well as functionality of the safety features. Figure 25 shows the arrival of the battery truck ECAT. Figure 26 shows the CNG truck CCAT during site acceptance test.

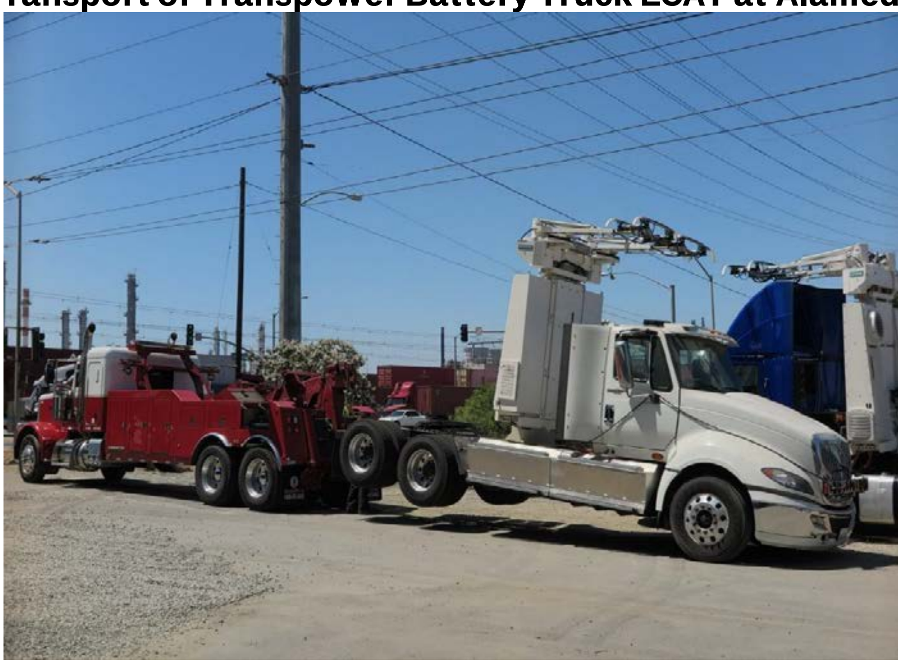
The system configuration of the site acceptance tests consisted of:

- The pre-tested pantograph system on the Transpower trucks
- The pre-tested hybrid drives and batteries on the Transpower trucks
- The pre-tested and commissioned external DC 600 V power supply as substation
- The commissioned overhead contact line on the test track

The corresponding Volvo tests were performed at the German eHighway test site at Gross Doelln, prior to an initial testing phase for the hybrid drive system (see chapter 2.9).

After the site acceptance tests were successfully completed for three different types of hybrid electric trucks and the catenary, the whole system was ready to demonstrate a zero emission corridor along the Alameda Street.

Figure 25: Transport of Transpower Battery Truck ECAT at Alameda Street Site



Source: Siemens AG Deutschland

Figure 26: Transpower CNG Truck CCAT During Site Acceptance Test

Source: Siemens AG Deutschland

2.9 Catenary Truck and Infrastructure Demonstration

This task can be considered as the technical core of the project as it serves to study and demonstrate maturity and reliability of the electric power supply of hybrid trucks via a catenary system. The task is subdivided in three main topics:

- Component integration testing of the MACK truck in Germany (see chapter 2.9.1)
- System integration and performance testing on Alameda Street with all hybridized trucks
- Catenary system safety analysis to evaluate potential hazards and mitigation measures related to the catenary system (see chapter 2.9.3)

2.9.1 Component Integration Testing in Germany (Task 9.1)

After the factory acceptance test (FAT) in Gothenburg/Sweden, the MACK truck was transported to the e-Highway test site in Gross Doelln/Germany before it was shipped to Los Angeles. Thus the first dynamic functions of the truck were tested, and it was possible to prove that the pantograph system can operate on different catenary system as long as their key parameters are in the interoperability range.

The integration and optimization works comprised the following aspects:

- Site acceptance test including safety functions and proof of correct integration
- Evaluation of vertical and horizontal working ranges
- Power transfer to hybrid drive system including optimization of the power split between the two electric driveline that form a combination of a parallel and serial hybrid drive (see Figure 6, Figure 24)
- Evaluation of acoustic emissions at different speeds

Figure 27: Test of MACK Truck at Gross Doelln Site 2016

Source: Siemens AG Deutschland

Figure 27 shows the MACK truck at the non-public eHighway test track at Gross Doelln north of Berlin. The substation is situated in the side margin.

2.9.2 Testing on Site Alameda Street - Demonstration Phase and Testing

The system integration and performance testing was carried out during a 6-month period from June to December 2017. While specific integration and optimization task of the different trucks dominated the first month, later test weeks concentrated on the performance testing that followed the required test items according to the statement of work[6]. Table 2 lists the required test items - the descriptions and the results of the tests were included in the SCAQMD contract 14062 Test Report Q4.

Table 2: Test Items According SCAQMD Contract 14062 Test Report Q4

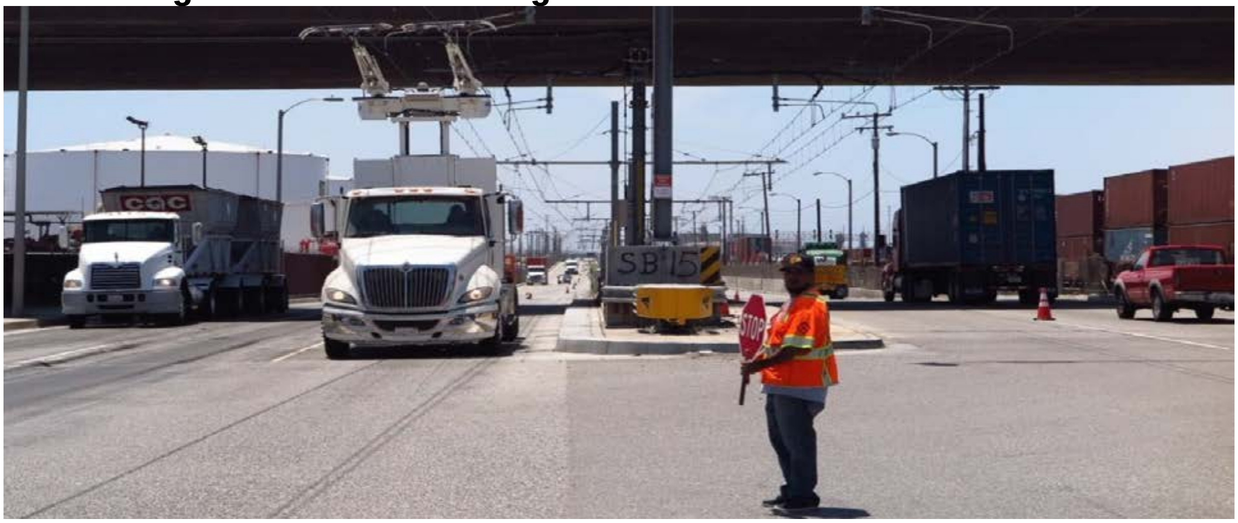
Item	Test description
A1	Infrastructure commissioning tests
A2	Energy efficiency testing
A3	General truck performance testing
A4	Pantograph performance and contact quality
A5	Drive in / drive out testing
A6	Overtaking testing
A7	Emergency braking testing
A8	Operating at the edge testing
A9	Proof of fail-safe pantograph design
A10	Ergonomics testing
A11	Weather and ambient condition test
A12	New algorithm testing*

Source: Siemens AG Deutschland

Test planning and actual execution had to consider specifics of a heavily used truck route. For a number of integration and performance tests the electrified lanes had to be reserved and closed by traffic management (see Figure 28), which turned out to be very hard to enforce as can be seen in Figure 29.

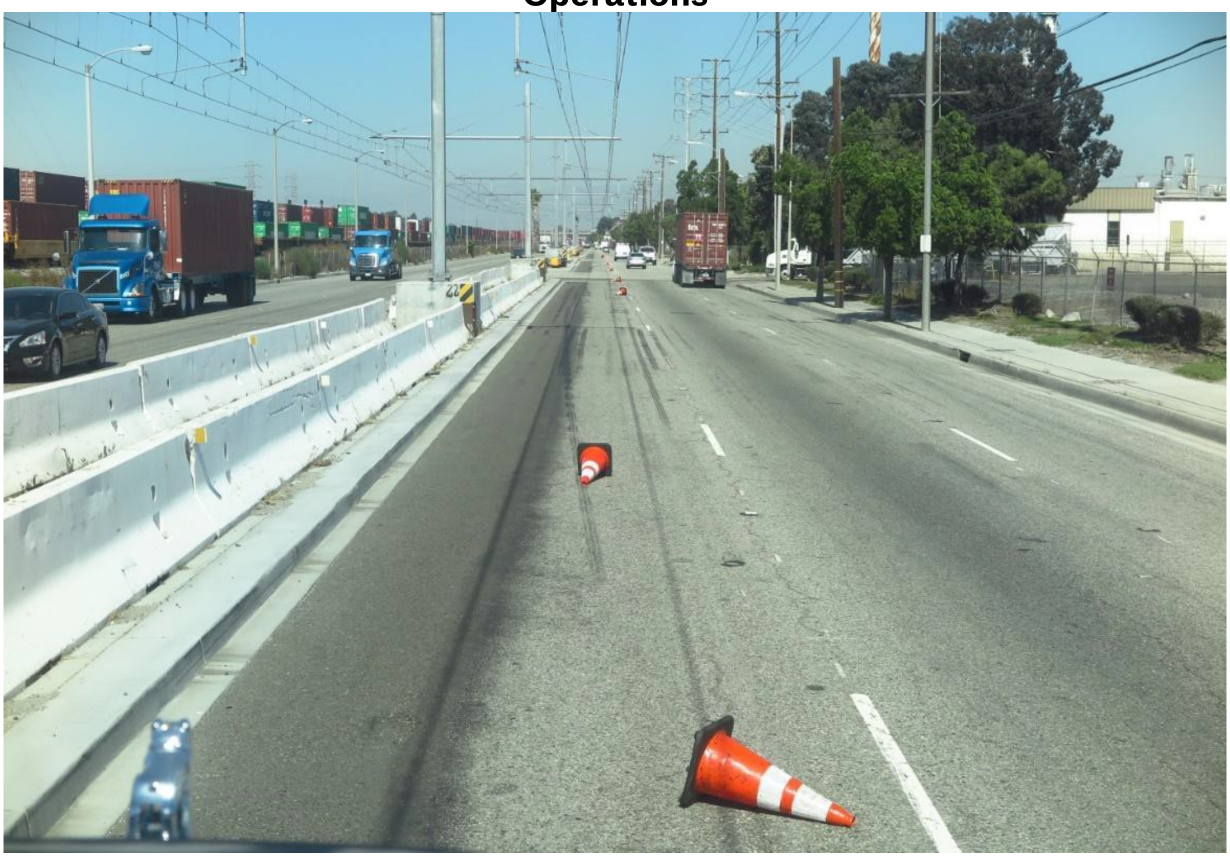
6 *SCAQMD:* Contract No. 14062 incl. Statement of Work. Diamond Bar 2014

Figure 28: Traffic Management in Place in Both Directions



Source: Siemens AG Deutschland

Figure 29: Cones Overrun By Traffic in Other Lanes and Troubling Test Operations



Source: Siemens AG Deutschland

Moreover, at different times testing had to be coordinated with road works by third parties, which occasionally limited availability of one of the directions on Alameda Street as shown in Figure 30.

Figure 30: Road Works on Southbound Stretch of Electrified Section

Source: Siemens AG Deutschland

2.9.3 Catenary System Safety Analysis (Task 9.4)

The introduction of a catenary system into public road infrastructures for tramway, trolleybus, and electric truck applications raises a number of safety related concerns. While all safety rules, standards, and project specific safety procedures could be transferred from existing electric public transport applications further topics were studied in detail in the related research projects in Germany. Hence the catenary system safety analysis can be derived in a three-step approach:

- Review of existing catenary system safety engineering methods and adaption of the overhead contact line design for road and highway applications
- Performance of an Operating and Support Hazard Analysis considering the project specifics for the 1-mile stretch on Alameda Street corridor
- Review and provision of discussion regarding process and results of the technical assessment of the catenary system by the German Federal Highway Research Institute (BASt – Bundesanstalt für Straßenwesen)

The key aspects of these work streams are explained in the following sub-chapters.

Review of Existing Catenary System Safety Engineering Methods

Design, construction, and operation of catenary systems are very mature and based on vast experience of more than 100 years of expertise. The experience contributed to a wide set of system, product, component, material, and testing standards that are likewise applicable for rail and road applications. In the course of eHighway related research projects, delta analyses were performed to identify additional risks and mitigation measures that result specifically from the highway application context.

One key finding was the mitigation of risks related to broken contact wires. In railway applications the broken contact wire falls to the ground and triggers a short circuit which is then detected by the substation and triggers the switch to interrupt power supply immediately. As road surfaces are not conductive enough this procedure is not applicable. Moreover, the coiling wire forms a mechanic obstacle. As a mitigation measure the dropper spacing was revised to three meters to prevent the contact wire from falling down. This measure was tested by cutting the wire, as shown in Figure 31.

Figure 31: Reduced Dropper Spacing Prevents Broken Wires Falling to Ground

Source: Siemens AG Deutschland

To prevent further trucks from running into the defect section with raised pantographs an optional broken wire detection system can be used. This is installed at the tensioning devices and can detect broken wires. This signal can then be transferred to the substation and triggers the switch to de-energize power supply.

Operating and Support Hazard Analysis

In the course of the Alameda Street demo project a mandatory (operating and support hazard analysis) was performed and discussed with the stakeholders. Besides the inherent safety related design methods already observed in the design of the catenary system, project specific hazards were identified and mitigated by technical or organizational measures. Technical measures included the application of crash barriers and absorbers along the median to reduce the severity of potential vehicle crashes into the foundations of the poles, as shown in Figure 32. Further topics included operational measures like coordination with third parties when road works are necessary and involve the usage of machinery in the vicinity of the catenary system (see Figure 33).

Figure 32: Crash Absorbers at Beginning of Electrified Section (Left) and Guard Rails (Right)

Source: Siemens AG Deutschland

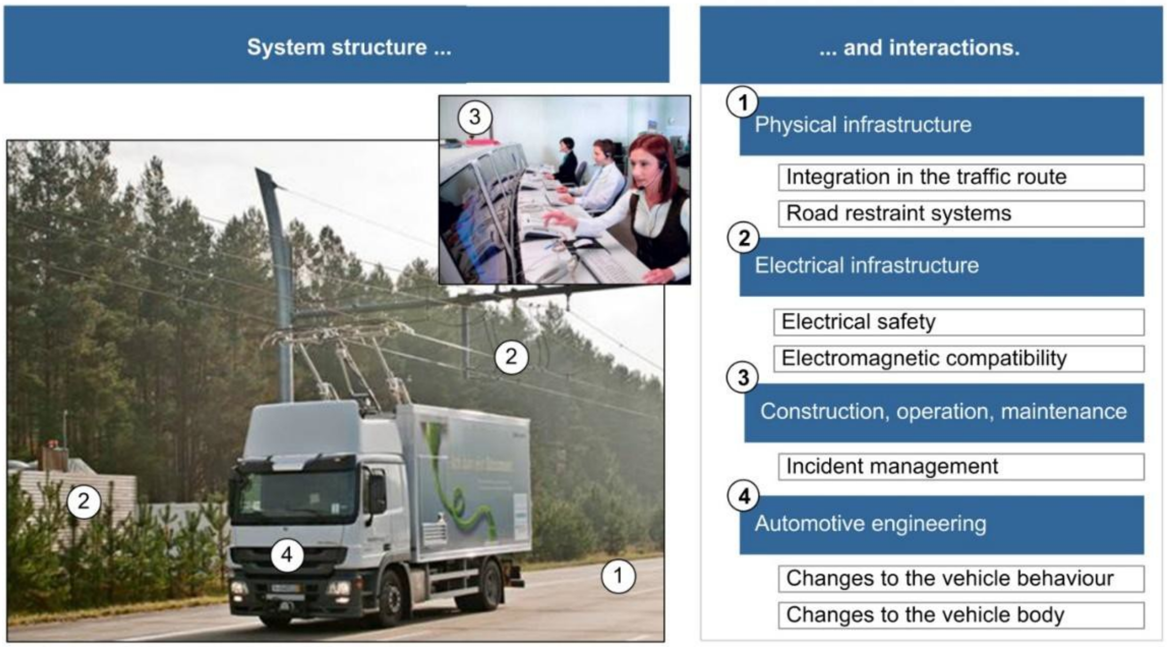
Figure 33: Road Works with Machinery in the Vicinity of the Contact Line

Source: Siemens AG Deutschland

Integration Assessment of the eHighway-System with Authorities

The interdisciplinary analysis and assessment of the traffic-related aspects of the eHighway technology for identifying normative and legal regulatory scope, and for deriving requirements and design guidelines were some of the main objects of the ENUBA 2 research project. Therefore, the Federal Highway Research Institute (BASt) was appointed to examine and assess the feasibility of this technology and its ability for integration into existing highways. The BASt is a scientific advisory authority subordinate to the German Federal Ministry of Transport and Digital Infrastructure. The starting point of the assessment was an overview of the system structure, and its significant interactions with the structural, electrical, operational, and vehicular environment, as exemplified in Figure 34. The system structure and its breakdown into four subsystems were very similar to the well-known electrically powered passenger and freight transport systems and are transferable to the set-up for the eHighway as carried out on Alameda Street (see also Figure 2).

Figure 34: System Structure for Electrified Freight Transport and Significant Interactions



Source: Siemens AG Deutschland

As shown in Figure 34, the integration of the overhead contact line infrastructure into the public road system, as well as pantographs and hybrid drive technology in trucks raise a number of questions regarding the requirements and general conditions for the modified construction and safe operation of the transport system. Within the scope of the technical assessment process, these issues were systematically analyzed and discussed by the research partners Siemens AG, Technical University Dresden and German Aviation Center (DLR), together with the automotive consultant company EDAG, who acted as a technical knowledge provider from the automotive industry. Their joint findings were then submitted to the Federal Highway Research Institute for review. Within the scope of this technical assessment process, all identified aspects and sub-questions were assigned to a total of 20 individual topics, which were then grouped into four main areas (TBs) assigned to the subsystems as shown in Figure 34:

- TB 1 - Road infrastructure
- TB 2 - Electrical infrastructure
- TB 3 - Construction, operation and maintenance
- TB 4 - Vehicle technology

Table 3 lists the total of 20 topics investigated under those four main groups.

Table 3: Assignment of the Investigated Topics to the Main Groups

Group	Number	Title and focal points
TB 1	TB 11	Clearance height under structures, derivation of the standard height and special constructions
TB 1	TB 12	Oversized transports up to 4.5 m
TB 1	TB 13	Statics of catenary poles taking into account the lateral clearances
TB 1	TB 14	Statics of bridge structures, assessment of the feasibility of electrification
TB 1	TB 15	Requirements for guard rail system
TB 1	TB 16	Crash test to verify the recommended guard rail system
TB 1	TB 17	Visibility of road signs
TB 2	TB 21	Integrated electrical protection concept including technical vehicle systems
TB 2	TB 22	Integrated EMC concept, including requirements for the technical vehicle systems
TB 2	TB 23	Emergency shutdown of the overhead contact line system
TB 3	TB 31	Construction concept
TB 3	TB 32	Maintenance concept
TB 3	TB 33	Technical monitoring and user authorization
TB 3	TB 34	Incident management / rescue concept
TB 3	TB 35	Hazards caused by ice on the overhead contact lines
TB 4	TB 41	Evasive maneuvers and changes in the vehicle dynamics
TB 4	TB 42	Changes in crash behavior of eHighway trucks
TB 4	TB 43	Changes in the fire behavior of eHighway trucks
TB 4	TB 44	Restrictions regarding the transport of hazardous goods
TB 4	TB 45	Length increase for semi-trailer truck to 17.0 m

Source: Siemens AG Deutschland

In these areas, individual reports examine in detail which general conditions can be assumed for the electrification of roads and trucks, and which requirements have to be fulfilled for a safe system design. The concepts were worked out in the following steps:

- Description of the state of the art in road traffic, taking into account databases of infrastructure elements, or collection of field data
- Description of the state of the art in electric rail traffic, including trains, trams and trolleybuses

- Synthesis of the general conditions and identification of the aspects relevant to electrified road freight traffic
- Preliminary planning or description of exemplified solutions
- Generalization and formulation of requirements
- Definition of the criteria for verifying the requirements and formulation of the general conditions for a trial in the public domain

The intense technical assessment process involved over a period of three years a multitude of workshop days, additional testing and a detailed results reviewing phase.

The results clearly showed that the electrification of road sections with a high share of heavy goods vehicles and the equipment of heavy commercial vehicles with pantographs is a technically feasible option for electric heavy road haulage.

The comprehensive consideration of the interactions of the subsystems with one another and with the existing transport infrastructure environment and the traffic flow did not reveal any aspects that fundamentally object electrification. The relevant requirements, general conditions, and assessment criteria were formulated during the development of the single topics. In many cases, customized investigation and assessment methods were developed that can also be used for individual projects.

Depending on the scope of the overall project for the construction of a catenary system as part of a highway, it must be assumed that a construction permit procedure, possibly in conjunction with a regional traffic and development plans, and further infrastructure approval procedures will have to be observed. Some of the permitting procedures may involve an environmental impact investigation.

The type of approval procedure and the scope of planning documentation that has to be submitted must be agreed at the start of the planning work with the responsible road infrastructure authority.

Major aspects of the planning require an initial, detailed viewing and analysis of the route in terms of:

- The characteristics of the roadsides, such as embankments, cuttings, and junctions
- The recording of the height restrictions created by road signs and overpasses
- The recording of the bridge structures along the route and assessment of their design and state
- The recording of the existing guard rail systems and noise barriers
- The preliminary planning of the contact line and power supply in order to determine the locations of the substations and to select the locations of the control terminals for emergency shutdown of the contact line

If necessary, a certified civil engineer is required to approve the construction documentation for the catenary system. Furthermore, in the course of the planning phase, contact persons must be appointed to work out and agree on the incident management, agree on the construction concept, and work out and agree on the maintenance concept for the catenary system.

Depending on the size of the vehicle fleet that is to be employed, certain steps have to be taken in the development phase for the project planning, construction, and approval of hybrid trucks with pantographs. The company distributing the vehicles plays a key role as it has to obtain the vehicle approval of the certification authorities.

2.10 Determine Owner and Operator of System

The SCAQMD is currently demonstrating the technical feasibility and performance of a unique catenary system capable of serving on-road heavy duty trucks, enabling extended zero emission operation for this challenging vehicle segment. As part of the demonstration program, SCAQMD has engaged entities that could become operators of future catenary systems in the South Coast Air Basin to assess their interest and the potential challenges to a sustainable business case for such catenary systems. This assessment was made through a survey of three potential system operators. The three organizations selected for interviews were down selected from six agencies considered. A summary of the initial matrix of the six potential survey participants is summarized in Table 4. The matrix was developed based on GNA's preliminary research and assessments of each organization and reviewed by South Coast AQMD staff before down selecting participants. Based on this initial matrix, Southern California Edison, LA Metro, and Cofiroute USA were selected for initial outreach and requested to participate in the survey. These three organizations represented a mix of organization types and experience that would be useful in garnering a broad range of perspectives on the opportunities and challenges of a catenary system.

Table 4: Matrix of Potential Survey Candidates

Operator	SCE	LA Metro	CalTrans	Cofiroute USA	Edison International	Gateway Cities COG
Organization Type	IOU	RTA	State Agency	Private Company	Private Company	JPA
Financial Capacity	Moderate / High	Moderate	Moderate	Unknown	High	Limited
History of Asset Ownership	High	High	High	Low/ Unknown	High	Low/ Unknown
Roadways Experience	Low	High	High	Unknown	Low	Low/ None
Electrical Infrastructure Experience	High	Low	Unknown	Low/ Unknown	High	Low/ None
Tolling Experience	Low	Moderate	Unknown	High	Low/ Unknown	Low/ None

Source: Siemens AG Deutschland

Southern California Edison is the primary investor-owned utility (IOU) in Southern California and is the electrical utility for properties along the I-710 corridor; the corridor used for the business case assessment provided by Siemens and South Coast AQMD as the basis for the survey.

LA Metro is the regional transportation agency (RTA) for Los Angeles County. Other similar organizations in Southern California include the Orange County Transit Authority, Riverside County Transportation Commission, and San Bernardino County Transportation Authority. LA Metro currently operates the Express Lanes on the I-110 freeway and light rail systems powered by catenary. Additionally, the I-710 corridor is within the LA Metro region and currently under planning by LA Metro for expansion. Consequently, LA Metro was selected as the regional transportation agency for this survey.

Cofiroute USA is a private company currently providing tolling and tolling infrastructure maintenance on the 91 Toll Roads through Orange and Riverside counties. Cofiroute is a subsidiary of a larger company, Vinci Concessions that may also be a potential partner in the development and operation of a catenary system for on-road trucks.

2.11 Survey Approach

Given the complex nature of the business case for a catenary system and the many technical questions that could arise during the survey, each survey was conducted in person. An introductory presentation was prepared and given to each participant to describe the technology and the conceptual business case. A copy of this presentation is attached to this memorandum. An open discussion with the survey participants then followed the presentation.

A series of questions were presented to each participant as part of the open discussion and the survey participant's perspectives were recorded.

- What operations would your organization be interested/capable of managing; Construction, Tolling, System Maintenance, Financing, User support
- Do you have a preferred or recommended structure for managing risk amongst system builders, owners, operators, and users?
- Do you feel the proposed revenue/margins are reasonable? If not, what is a typical margin you would seek from this type of project?
- What are the greatest risks to the project's long-term viability/success?
- Do you see this technology as competitive with zero-emission alternatives in the long-term?

2.12 Survey Responses

The mix of survey participants elicited a diverse range of perspectives. However, certain common themes emerged from the discussions. These common themes are discussed below and are followed by additional summaries of responses from the individual survey respondents.

2.12.1 Common Themes

Each of the survey participants was generally open to serving a role in the development and/or operation of a catenary system, should it be built. However, each of the survey participants recognized two central issues to the business case for the catenary system; adoption of the catenary technology by private operators, and long-term competition with other electrification technologies.

Adoption of catenary-enabled trucks – All survey participants raised questions about the incentives and costs to private fleets to equip their trucks with pantograph systems and electrified drivetrains to access the catenary system. In particular, there was concern that the incremental costs to the fleet would be too high to allow for adoption of the technology without a forcing regulation or substantial incentives. Additionally, the adoption rate was a concern as the system might not generate sufficient tolls to cover system maintenance and operation until a substantial number of trucks were subscribed to the system.

Competitiveness with other zero-emission technologies - The survey respondents were concerned about the lead time for the creation of such a system along a dense urban freeway like the I-710. Such a system could take years or decades to complete. In parallel, battery-electric and fuel cell technologies are expected to improve and would represent significant competition to a catenary system for local/regional travel.

While the business case prepared by Siemens highlights the potential for a functional system, once it is constructed and sufficiently subscribed, the consensus of the survey respondents appears to be that a more thorough examination of timing and competitiveness issues would be worthwhile. Alternatively, if commitments from one or more large truck fleets to utilize the system could be secured, many concerns over the viability and risks of a catenary system could be mitigated.

Despite intense stakeholder dialogue and high public attention during the demonstration phase, see chapter 8 – Public relation, it was not possible to determine ways for uninterrupted ownership and operation of the demonstration site along Alameda Street. Therefore, the decommissioning according task 12 (see chapter 5.12) was carried out.

2.13 Project Management and Reporting

During construction and commissioning all required reporting was provided up to the stoppage of work as stated below and in chapter 3.1. Once truck testing was underway, reporting was provided as required.

General adherence to schedule can be summarized as follows:

- The schedule was kept up until local utility SO Cal Gas required the TPSS to be moved due to California State law enacted January of 2016 wherein encroachment within an easement of a high pressure gas line was illegal. This caused a stop in the work for six months until the SCAQMD negotiated a six-month period for testing of the pantograph equipped trucks on the OCS System on Alameda Street.
- Once the test period was granted the trucks were tested from July 1, 2017 through January 3, 2018 with the outcome as previously noted.

- Upon completion of the six-month test period the contract was changed to reflect the test period as defined.

2.14 System Decommissioning and Site Restoration

While evaluation of the project results and compilation of the final report this task was still ongoing.

The Decommissioning of the site is currently underway. The requests for proposals (RFP) have been provided to three contractors with work instructions and site review. Answers to these RFPs are currently being entertained.

Permits are currently being sought for the scope of work through the City of Carson and provisions are being made for the offloading and disposition of the site equipment.

CHAPTER 3:
Challenges Findings Recommendations

Proving technical maturity and technological supremacy compared to other electric road systems, for example, ground rail or inductive power transfer, for freight haulage was one key goal of the project. The second goal was to actually see and learn about catenary infrastructure installation in an industrial public environment, pantograph integration into different hybrid vehicles and endured testing under real traffic conditions.

This chapter deals with the challenges that occurred during project execution, major findings related to the testing operations, and recommendations to be drawn to foster the implementation and development of catenary type truck haulage.

3.1 Challenges during Project Execution

Underground Infrastructures – Gas Pipelines

During the project execution it turned out that foundations for the poles which are supporting the catenary cannot be piled with steel tubes as this is common practice for catenaries. Further investigations surrendered that a gas pipeline was running embedded in the central reserve / median. This did not allow to pile the poles as was intended. The solution to overcome this challenge was to install the poles on pre-cast concrete foundations to get permission from the gas pipeline operator company. The necessary redesign did involve the contact line system as well as further median and road works.

Redesign and re-approval of the foundations caused a project delay of several months. Later on another gas pipeline underneath the substation was found to be critical for an extension of the testing phase as it limits accessibility to the pipelines for maintenance.

To cover up for both challenges it was mutually decided to intensify the testing phase and to shorten it to a six-month period. This reduction was necessary since the operational license for the substation could not be extended.

Interface to Truck Supplier

Integration of the pantographs into common class 8 trucks requires a comprehensive interface clarification. Also the challenge to adapt the combustion motor technology and to propel a truck with electric motors was underestimated. Although Siemens profited from the know-how made with other suppliers to integrate catenary power supply on heavy duty trucks in earlier projects, additional efforts and individual clarifications unique to the trucks equipped in the project were necessary to reach project goals. Finally and during system integration testing, individual minor adaptions in all subsystems including protection settings at the infrastructure could be found to stabilize truck performances. Future applications and efforts should strive to standardize that interface further and to generalize findings from integration and testing.

Truck #4

Contrary to original planning no agreements to purchase and hybridize a fourth class 8 truck from another truck OEM could be achieved. While negotiations took very long a positive agreement seemed certain. Therefore, it was mutually decided to purchase and manufacture all four pantographs in a row to benefit from resource synergies. After FAT the fourth pantograph was stored in Germany and is now being shipped.

Incorporation of Parallel Research Work in Germany

In parallel to the execution of the demonstration project on Alameda Street, research and development projects continued in Germany. As already discussed in chapter 2.9.3 safety related findings were incorporated in design and construction of the catenary system. Minor adaptions to the pantograph control, for example, optimized lowering procedure, were realized as well without influence on project schedule.

3.2 Findings during Testing Phase

Test Operation Related Findings

General findings related to the test operations were:

- Achieving and maintaining a sufficient level of stability for the entire system - substation, prototype vehicles, and pantographs - was a challenge during system integration and parts of the testing phase, that started in parallel to system integration. It required quick support from specialists as well as securing availability of special spare parts.
- The combination of the relatively short electrified track with the heavy traffic conditions made it hard for the drivers to accomplish specific test routines like full overtaking maneuvers or edge of lane testing without traffic interference.
- All trucks feature battery buffered electric drives that charge while driving. Given the traffic conditions and short electric run time in each drive it was very hard to repeatedly reach cruising speeds and steady states for the drivetrains.
- The sharp turns (U-turns) at Alameda Street were leading to increased trailer tires degradation and eventual stop of trailer operations in early December.

Truck Related Findings

While the reliability of the prototype trucks has been well sufficient to support the data collection and performance testing activities, the following observations are worth highlighting:

- Electrified truck auxiliaries (24 V/12 V batteries, air compressors) remain key assets of vehicles without auxiliaries powered permanently by diesel engines. This accounts especially for the air compressor given the higher air supply needs due to the higher contact line height and the rough road. More powerful compressors would be helpful to avoid overload the auxiliaries.
- The main battery systems of contact line powered vehicles show significant differences in the use cases and electric cycling, calling for increased maintenance time for battery

balancing. Future designs should include other cell types specifically designed for static and dynamic charging.

- Maintaining proper alignment of the vehicle with the infrastructure at all times to prevent loss of contact has proven to be challenging in certain driving situations. Therefore, further deployment of electrified roadways along freight corridors should consider integration of vehicle automation technologies to assist the driver, such as assisted steering, automated positioning in lane center.
- The cycle times of pantographs – especially for connection – are relatively long and should be optimized in future designs.
- Studying driver ergonomics revealed that positioning of the displays and necessary involvement of the drivers to operate the pantograph can be optimized. In the mid-term automatic pantograph operation should be considered.

Infrastructure Related Findings

- With the current pantograph design and the given legislative framework (contact line height at 18 ft nominal) the pantographs operate at the vertical edge of their working range. Potential optimizations for future operation have been derived.
- Integration (esp. substation relay setting) of different vehicle types call for close cooperation of all subsystem specialists. The system integration findings have to be generalized as further detailed interface specifications towards the truck drivetrain integrators and the substation designers.
- Turn-outs and variable street layouts demand more complex catenary constructions and increase testing impact when closed lanes are required.

3.3 Recommendations for Research and Improvement

The eHighway is based on proven and mature technology, especially on infrastructure side. Nevertheless, compared with other transport systems, the eHighway is still a rather young concept with further development plans regarding system optimization. Further R&D works and steps towards higher TRL (technology readiness level) must be taken and are already planned. This is most important for industrialization and robustness of the pantographs and electric hybrid drivetrains optimized for heavy truck applications. Based on the challenges overcome, findings made, and discussions started with stakeholder the following recommendations can be derived:

Regulatory Framework

After the successful demonstration of the technical feasibility of the eHighway system the regulatory framework will need to be evaluated in further detail as it has a major impact on the commercial viability of future projects. The major aspects include taxation, emission charging, billing and accounting, infrastructure design, and approval guidelines.

Power Supply and Generation

The interfaces towards energy suppliers should be elaborated further with regards to market roles as infrastructure providers and operators as well as to further analyze and specify technical aspect. The topics to be considered comprise the shift to increase regenerative power generation, technical network connections aspect, power flow estimations and optimized system designs, energy metering and billing, and system operation and maintenance.

Others Use Cases

Beside the use of overhead lines by truck it could be also considered to adapt this technology to propel electric buses in private or public sector. This could increase the number of vehicles on electrified sections and open up synergies for design and production of electric drivetrains for commercial vehicles.

Truck Technology

The catenary technology can serve as an electric backbone for dynamic supply and additional charging of vehicle energy storage systems. To extend ranges beyond electrified sections for complete ZE cycles supplementary systems like on-board batteries, fuel cells, or synthetic fuels (for example, Power to Gas PtG or Power to Liquid) for combustion engines will be needed. Future work should simplify drivetrain combinations and head for mutual optimization of energy storages to gain vehicle designs matching the designated applications.

The vehicle built by Volvo for this project was a technology demonstrator intended to represent an eHighway enabled vehicle. The vehicle included several technologies not ready for commercialization and was optimized for maximum flexibility with regards to operating modes.

With the experience gained both in terms of technology and operating conditions during this demonstration, substantial design improvements were identified with regards to complexity, weight, and reliability for this specific application.

The primary areas to be addressed in future works include:

- Vehicle power distribution system where number of energy conversion steps can be greatly reduced.
    - This would lead to a less complex electric mechanical propulsion topology.
- Joint optimization of vehicle and pantograph design aimed to reach a globally optimal design.
    - This would lead to a less complex interface and control of connection / disconnection of pantograph.

Endurance Tests and Increased Testing Conditions

During the development of the eHighway components and products comprehensive tests were conducted and proved road stability adequately matching the development stages.

Nevertheless, the existing contact line sections in demonstration projects are too short to gain endurance test results. Future field trials already feature longer electrified sections and increased truck operations to achieve more mileage as a better base to evaluate and improve robustness.

In order to further increase the maturity of the concept, future testing should include a broader operating context where both dynamic events such as entry/exit of the eHighway at higher speeds as well as steady state conditions can be studied in more detail.

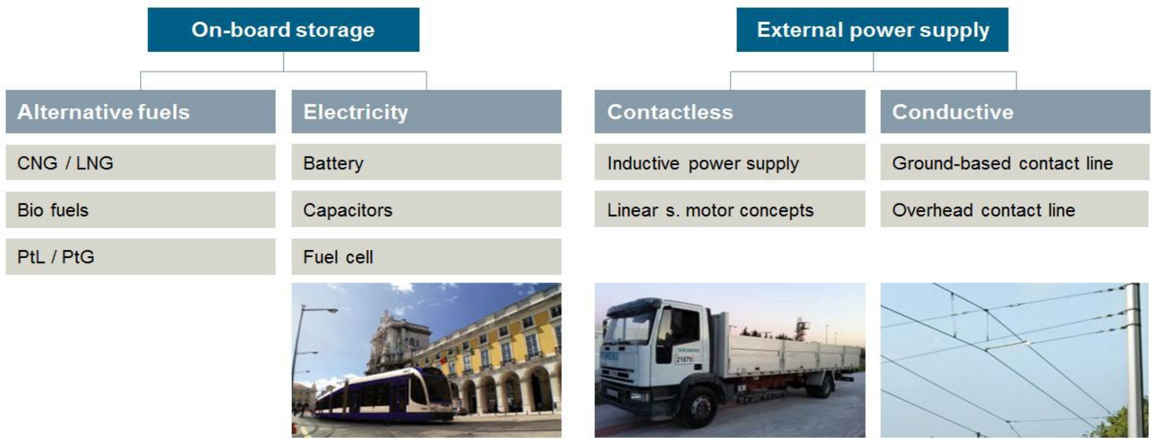
This would require an enhanced test track setup which should preferably be defined jointly by infrastructure, vehicle provider and local authorities. Some desired characteristics of such test tracks known from vehicle providers include at least above 40 km as well as variation in road grades (+/- 3-5%) to better represent long haul vehicle operation.

CHAPTER 4: Assessment of Project Goals

4.1 Zero Emission Goods Movement Technologies

Zero emission freight haulage technologies comprise solutions with on-board energy storages based on alternative fuels or electricity and solutions with external power supply, see Figure 35.

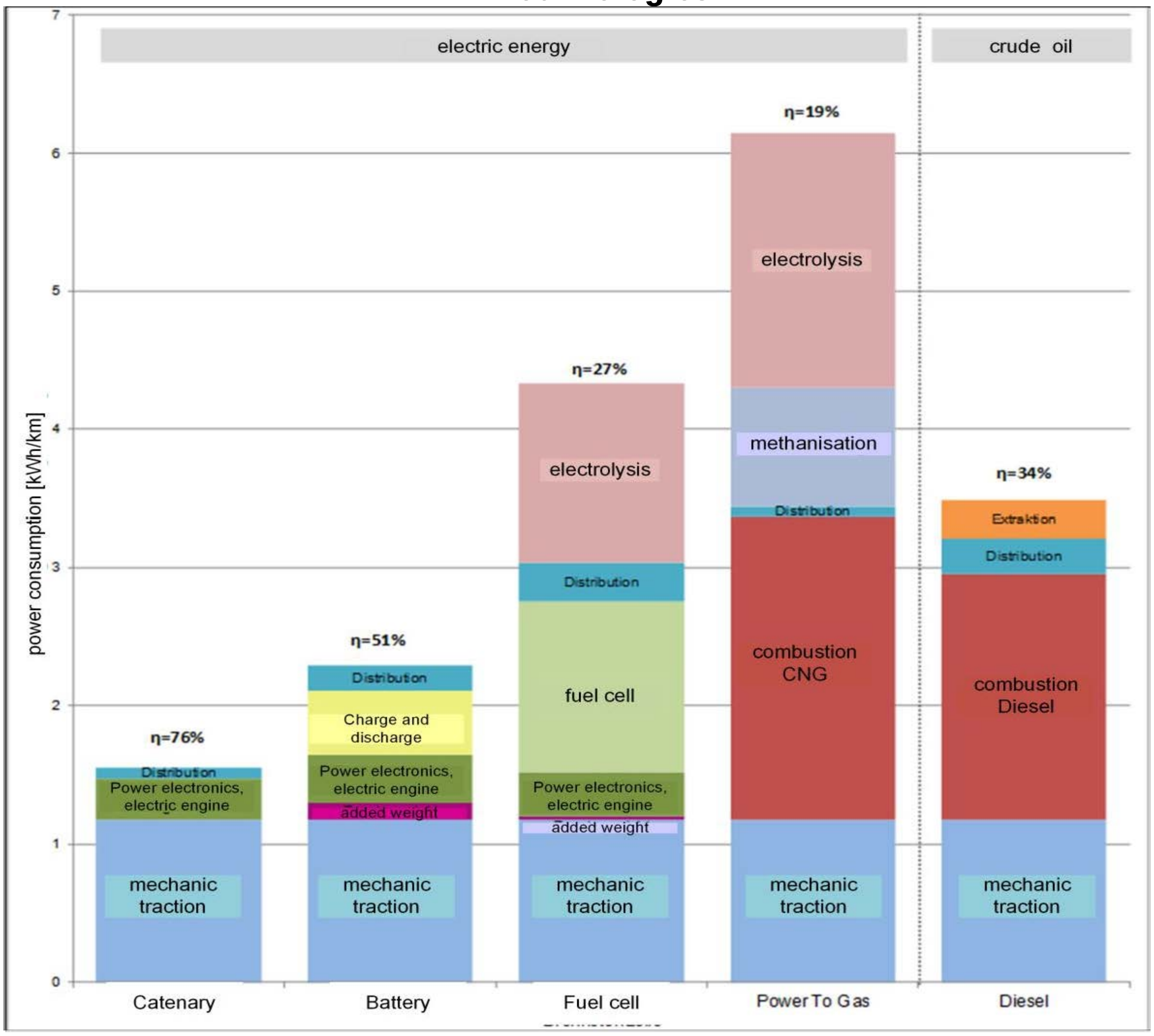
Figure 35: Zero Emission Technology Matrix for Road Freight Applications



Source: Siemens AG Deutschland

A key driver to determine applicability and to differentiate the solutions is a closer examination of the overall efficiencies, Figure 36.

Figure 36: WTW Efficiencies as Specific Power Consumptions of Different ZE Technologies



Source: Siemens AG Deutschland

Analysis of Figure 36 allows the following conclusions:

- External power supplies by means of catenary systems are by far the most efficient technology.
- Batteries are still more efficient than conventional diesel traction, but will always be limited by ranges, additional weights and production and lifecycle related emissions.
- Hydrogen fuel cell systems and synthetic fuels (e-fuels) are characterized by unduly low efficiencies, see also Figure 1.
- To achieve an acceptable efficiency level compared to conventional diesel traction a blend of technologies is necessary with highly efficient direct electricity use on electrified core network sections and extension of electric range by batteries or synthetic fuels.

Electrifying core corridors and heavily used truck routes can be a catalyst towards environmental friendly but still economically feasible ZE freight system.

4.2 Most Viable Technology

As shown in the overview in Figure 35 different external power supplies can be discussed. Typically, they are summarized with the term ERS – electric road systems and comprise the following technologies:

- Power supply via overhead contact line systems (catenary)
- Inductive energy transmission
- Power supply via a ground-based (earth) conductor rail

Figure 38 characterizes these different technologies by explaining power transmission principles and a short discussion of advantages and disadvantages. Further state-of-art information on all types of ERS is assembled in the report[7]. Based on the scale of the existing public demonstrations on Alameda Street corridor and E16 highway in Sweden as well as the planned field trials in Germany the catenary type power supply can be considered as the most mature ERS technology. Moreover, transmission efficiency on the contact point between infrastructure and vehicle reaches 99 percent[8] and is much higher than the inevitable transmission losses in inductive solutions.

With specific consideration of the heavy truck volumes that are discussed for ZE corridors ground-based conductor rails must be questioned regarding their integration into the road surface. While lane grooves can be compensated by vehicle suspensions and the pneumatic pantograph mechatronics in overhead contact line applications such distortions (see Figure 37) cannot be handled by integrated conductor rails.

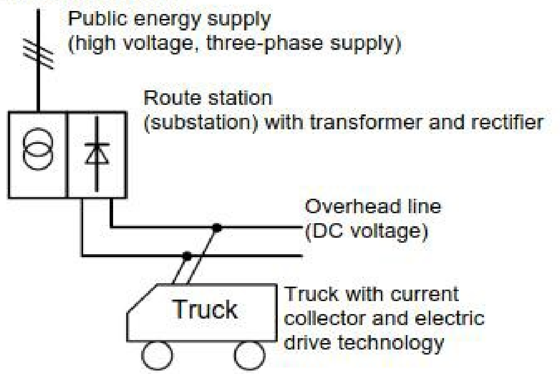
Figure 37: Lane Grooves on Alameda Street at Intersection

Source: Siemens AG Deutschland

7 *SINTEF Energy Research:* Technology for dynamic on-road power transfer to electric vehicles – Overview and electro-technical evaluation of state-of-the-art for conductive and inductive power transfer technologies. Project: ELinGO – Electric infrastructure for Goods Transport. Project report Version 1.2, Oslo, January 2018.

8 *Lehmann, M. et. al.:* Untersuchung eines Stromabnehmers für schwere Nutzfahrzeuge. In: eb - Elektrische Bahnen, Jg. 111 (2013) H. 11, S. 657ff

Figure 38: Comparison of Technical Features of ERS Power Transfer Technologies

<table>
<tr>
<th>Overhead line
Grid-bound transmission of electr. energy with an overhead line</th>
<th>Inductive energy transmission
Transmission of electrical energy through induction of electrical voltage</th>
<th>Earth conductor rail
Transmission of electrical energy through a rail beneath the vehicle</th>
</tr>
<tr>
<td>Schematic sketch

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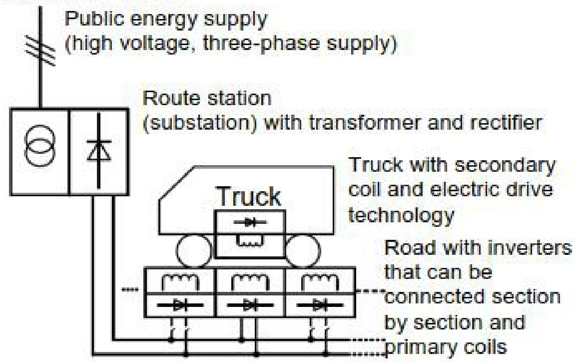
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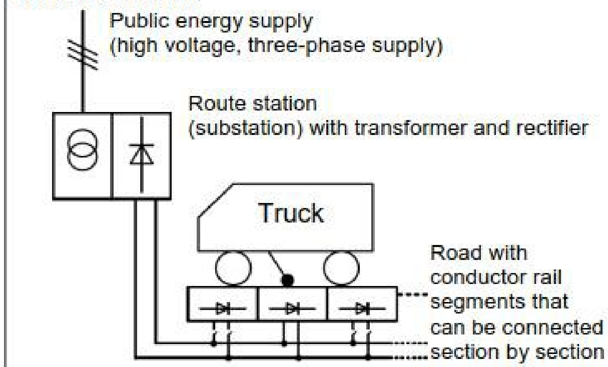
</td>
</tr>
<tr>
<td>Operating principle
- from power supplies in substations, DC voltage is generated for feed into overhead line
- Trucks are equipped with current collectors and transmit current from the overhead line to the drive system
- Trucks are equipped with power electronics, an electric motor and energy storage system
- Vehicles can exchange energy gained via the overhead line when braking or feed it back into the upstream grid</td>
<td>Operating principle
- from power supplies in the substations, DC voltage is generated for feed into the supply line
- Route is divided up into segments that can be connected section by section
- Trucks are equipped with coil systems (secondary coils) in which electr. voltage is induced and energy is transferred when overlapped with the road coil
- The trucks are equipped with power electronics, an electric motor and energy storage system</td>
<td>Operating principle
- from power supplies in substations, DC voltage is generated for feed into conductor rails
- Route is divided up into segments that can be connected section by section
- Trucks are equipped with current collectors and transmit current from rails to the drive system
- Trucks are equipped with power electronics, an electric motor and energy storage system</td>
</tr>
<tr>
<td>Advantages
- Easy to integrate current collector/drive technology
- DC or AC voltage possible
- No notable electromagnetic influence with DC systems
- proven technology, 120 years of experience
- no direct intervention into the route required
- mobile current collector can offset vehicle movements in the lane without any energy loss
- distance of the substations approx. 1-4 km (no additional switches and route installations required)
Disadvantages
- visible overhead line above the electrified lane</td>
<td>Advantages
- no visible overhead line, road transport remains virtually unchanged visually
Disadvantages
- extensive installations in the road per segment
- EMV critical, given the alternating field
- coil systems must be traversable by trucks (mechanically heavily loaded lane)
- the top/base layer required for this increases the distance between the road and vehicle coil and lowers efficiency
- longer road segments that are not completely overlaid by vehicles have poor efficiency</td>
<td>Advantages
- no visible overhead line, road transport remains virtually unchanged visually
- good efficiency due to conductive energy transmission
Disadvantages
- extensive installations in the road per segment
- rail systems must be traversable by trucks (mechanically heavily loaded lane)
- weather conditions such as snow and ice or contamination can significantly worsen the electrical conductivity
- individual vehicle movement on a stabilization level is either difficult or impossible to achieve without subsequent damage due to rigid current collector coupling</td>
</tr>
</table>

Source: Siemens AG Deutschland

4.3 Conclusions and Perspectives

The project has demonstrated that the eHighway system can be implemented in an existing road infrastructure as a potential zero emission goods transport technology. During the testing phase, the eHighway system proved to be a viable technology suitable for regional zero-emissions corridors. The whole project and the testing gained wide interest by stakeholders and potential users, see Figure 39.

Figure 39: Catenary Supplied Hybrid Trucks Raise Attention of Key Stakeholders for ZE Transport

Source: Siemens AG Deutschland

Lessons learned from this project and from the eHighway related activities of Siemens and its cooperation partners are being implemented in the ongoing development and improvement. A strong focus will be put on a new generation of the pantograph system which is to be released for the field trials on German highways in 2019. The modifications are targeting at reducing the weight and complexity of the pantographs in order to increase the availability while at the same time reduce the costs.

During the recent years, the eHighway system is increasingly being considered as the backbone technology - not only for shuttle applications in ports and mines, but although as core solution to reach ambitious climate protection and emission reduction targets.

When larger distances of highways are being electrified with overhead contact lines, there will remain a share of the routes where the vehicles have to utilize their alternative drive system. Besides batteries and synthetic fuels used in conventional or down-sized combustion engines small fuel cell systems may be used, if this technology proves out feasible and cost-compatible in the future. The adaptation of the trucks to the specific needs of the logistics companies offers great potential to achieve ZE road freight transport while at the same time foster the development of these technologies.

Larger scale projects also offer potential to reduce infrastructure costs significantly as discussed in the business cases for further applications in Southern California.

CHAPTER 5: Public Relations and Communication

5.1 Press and Media Releases

The feedback from public media, internet platforms and TV stations on the project were positive. The TV report from Discovery Canada has given a comprehensive overview of the goals and targets which were achieved during the project duration. The following Internet Links have been published after the opening of the eHighway on the Alameda Street:

- SoCal Siemens Inc Newsroom (November 8, 2017)
- Siemens eHighway Runs for SoCal, Fleets & Fuels (November 17, 2017)
- How about electric semis that draw power from overhead wires? Green Car Reports (November 20, 2017)
- Siemens Begins Zero-Emissions Highway Testing in California, Heavy Duty Trucking (November 13, 2017)
- First 'eHighway' Demonstration Project Under Way, Environmental Protection (November 20, 2017)
- California's First Electric Highway Is Finally Open, Green Matters (November 13, 2017)
- Siemens Begins Zero-Emissions Highway Testing in California, Trucking Info (November 13, 2017)
- Today's Pickup: California ports become testing ground for electrified highway, Freight Waves (November 13, 2017)
- One way to curb freight emissions: Put trucks on an electric catenary system, Ars Technica (November 10, 2017)
- Never Mind Electric Cars: Why Electric Roads are the Real Key to the Future, Inverse (November 10, 2017)
- Trucks start rolling down California eHighway, New Atlas (November 10, 2017)
- Siemens eHighway Heavy-Duty Trucks Continue in California, Clean Technica (November 12, 2017)
- Siemens debuts first electrified eHighway in the US, Gears of Biz (November 10, 2017)
- When overhead wires feed energy to trucks in California demo, Tech Xplore (November 10, 2017)
- Ports of LA and Long Beach Debut Hybrid Trolley-Trucks, The Maritime Executive (November 9, 2017)
- Siemens Unveils California's New Electric Highway, The News Wheel (November 12, 2017)
- This Week in Tech: An Electric Highway for Green Transportation, Architect Magazine (November 10, 2017)

- Today’s Pickup: California ports become testing ground for electrified highway, Freight Waves (November 10, 2017)
- First US eHighway demonstration in California, Energy News Live (November 10, 2017)
- California Builds First Electric Highway, For Construction Pros (November 9, 2017)
- First U.S. eHighway Electrified Trucks Running in California, Construction Equipment (November 9, 2017)
- Syndication: America’s first eHighway goes live in California, Blouin News (November 10, 2017)
- Hybrid 'trolley trucks' debut in Port of LA, Long Beach, Fox 11 Los Angeles (November 9, 2017)
- This Electric Highway Powers Trucks Without Recharging
- Fast Company, November 9, 2017
- There's Now an Electric Highway In California Forbes, November 8, 2017
- eHighway broadcast coverage-ABC, CBS November 8, 2017
- Trolly-like system for heavy-duty trucks tested near the ports of LA, Long Beach Daily Breeze (LA local), November 8, 2017
- Siemens debuts first electrified eHighway in the US Inhabitat, November 9, 2017
- Siemens Tests Novel eHighway for Heavy-Duty Trucks in California Next-Gen Transportation News, November 8, 2017
- California Builds First Electric Highway
- Forconstructionpros.com, November 9, 2017
- First U.S. eHighway Demonstration Running in California, Mass Transit, November 8, 2017
- Siemens to Conduct eHighway Trials with Electric Volvo Trucks in California Inside EVs, November 9, 2017
- Electrified 'eHighway' demonstration running in California Utility Products, November 8, 2017
- Siemens Tram-Trucks Cruise Near LA Port, Port Technology, November 9, 2017
- Siemens launches the first eHighway demonstration in the U S

TV Reports

- Discovery Channel Canada 12-01-2018

5.2 Presentations to Customers and Stakeholders

During the construction and testing phases a number of technical presentations were held at the site. Table 5 lists these dates.

Table 5: Date and Topic of Customer and Stakeholder Presentations

Date	Topic
2015-12-22	Funding partners demonstration at substation and test track
2017-07-18	Port of Long Beach
2017-07-18	SCE – Technical Group 1
2017-09-07	AQMD Board Meeting
2017-10-14	4th International Moving Forward Network Conference
2017-11-08	Press and Media Event
2017-11-30	Discovery Channel Canada
2017-12-12	SCE – Technical Group 2

Source: Siemens AG Deutschland

GLOSSARY

CALIFORNIA ENERGY COMMISSION (CEC) - The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The Energy Commission's five major areas of responsibilities are:

- Forecasting future statewide energy needs
- Licensing power plants sufficient to meet those needs
- Promoting energy conservation and efficiency measures
- Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
- Planning for and directing state response to energy emergencies.

CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA - pronounced See' quah) Enacted in 1970 and amended through 1983, established state policy to maintain a high-quality environment in California and set up regulations to inhibit degradation of the environment.

COMPRESSED NATURAL GAS (CNG) - natural gas that has been compressed under high pressure, typically between 2,000 and 3,600 pounds per square inch, held in a container. The gas expands when released for use as a fuel.

ENUBA - Elektromobilität bei schweren Nutzfahrzeugen zur Umweltentlastung von Ballungsräumen (Electromobility for trucks - better environmental protection for agglomerations), Siemens' research project that aims to enable electromobility for heavy duty vehicles and to fulfill e-mobility's promise to reduce CO2 emissions and to improve local environmental statistics regarding pollution and noise.

FACTORY ACCEPTANCE TEST (FAT) - the functional test that is performed by the vendor upon completion of the manufacturing process to prove the equipment has the same specification and functionality that indicated in the datasheet, specification and purchase order. The test typically is witnessed by the third party inspector and customer representative (purchaser).

HUMAN-MACHINE INTERFACE (HMI) - the hardware or software through which an operator interacts with a controller. An HMI can range from a physical control panel with buttons and indicator lights to an industrial PC with a color graphics display running dedicated HMI software.

ORIGINAL EQUIPMENT MANUFACTURER (OEM) – A company that manufactures a product that is sold to another company, which resells the product under its own brand name.

OVERHEAD CONTACT LINE (OCL/OCS) – an overhead line or overhead wire is used to transmit electrical energy to trams, trolleybuses or trains.

PANTOGRAPH (PAN) - a jointed framework conveying a current to a train, tram, or other electric vehicle from overhead wires.

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT (SCAQMD) - the air pollution control agency for all of Orange County and the urban portions of Los Angeles, Riverside and San Bernardino counties. This area of 10,743 square miles is home to over 16.8 million people–about half the population of the whole state of California. It is the second most populated urban area in the United States and one of the smoggiest. Its mission is to clean the air and protect the health of all residents in the South Coast Air District through practical and innovative strategies.

SOUTHERN CALIFORNIA EDISON (SCE) -- one of the nation's largest electric utilities, which delivers power to 15 million people in 50,000 square-miles across central, coastal and Southern California, excluding the City of Los Angeles and some other cities.

SOUTH CALIFORNIA (SoCal) - a geographic and cultural region that generally comprises California's southernmost counties, and is the second most populous urban agglomeration in the United States. The region is traditionally described as eight counties, based on demographics and economic ties: Imperial, Los Angeles, Orange, Riverside, San Bernardino, San Diego, Santa Barbara, and Ventura. The more extensive 10-county definition, which includes Kern and San Luis Obispo counties, is also used and is based on historical political divisions.

TRACTION POWER SUPPLY STATION (TPSS) - an electrical substation that converts electric power from the form provided by the electrical power industry for public utility service to an appropriate voltage, current type and frequency to supply railways, trams (streetcars) or trolleybuses with traction current.

WELL TO WHEEL (WTW) – a specific LCA (Life-cycle Assessment) used for transport fuels and vehicles. The analysis is often broken down into stages entitled "well-to-station", or "well-to-tank", and "station-to-wheel" or "tank-to-wheel", or "plug-to-wheel". The first stage, which incorporates the feedstock or fuel production and processing and fuel delivery or energy transmission, and is called the "upstream" stage, while the stage that deals with vehicle operation itself is sometimes called the "downstream" stage. The well-to-wheel analysis is commonly used to assess total energy consumption, or the energy conversion efficiency and emissions impact of marine vessels, aircraft and motor vehicles, including their carbon footprint, and the fuels used in each of these transport modes. WTW analysis is useful for reflecting the different efficiencies and emissions of energy technologies and fuels at both the upstream and downstream stages, giving a more complete picture of real emissions.