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SCANIA

E-Mobility Complete Vehicles: A Layout and Modularization Approach

Master’s thesis in Product Development (MPPDE), 30 Credits

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Abstract

The transport industry is facing an extensive technological shift towards electrification to build an environmentally sustainable future. Scania, one of the leading players in the field of trucks is also working towards electrification of their vehicles through the use of their modularity. This thesis is aimed towards the modular approach of electrification of trucks from a long-term perspective. The purpose of this thesis thus is to analyze the existing modules of Scania trucks to determine which of these modules are not necessary for an electric truck, the modules that need to be either added or modified in order to satisfy the needs of electrification and to analyze the relations between these modules. This thesis aims to propose a new modular toolbox that can be shared between both Internal Combustion Engine (ICE) powered trucks and electric trucks. This thesis also aims to propose a strategical layout for an electric truck through placing these modules on the vehicle layout on a holistic level.

In order to achieve the said purpose, this thesis work is divided into three main chapters, pre study, nodular toolbox analysis and battery layout analysis. Pre study is aimed at getting an in-depth knowledge regarding Scania, modularization, ICE trucks and electric trucks. This was done through a detailed literature review and through conducting various interviews with experts from all the concerned fields. Modular toolbox analysis was aimed at identifying the affected modules while transitioning from ICE powered trucks to electric trucks. This chapter also deals with the relations between these modules and the strategic placements of these modules on a truck. This was done through benchmarking, literature review on recent technological developments, brainstorming and by conducting interviews with experts. Battery layout analysis was aimed at proposing a strategical layout for an electric truck from an energy storage perspective for different scenarios. This was done using CAD modeling and assembly in Catia V5.

Additionally, the results from these analyses were compiled and presented in the form of a new modular toolbox for electric trucks, strategical layouts for different scenarios and the amount of energy storage that can be placed on the truck for each scenario. Finally, some recommendations were given for the right way to move forward with electrification from a layout perspective along with some recommendations for future work that will bolster the finding of this thesis and take the research forward.

It is hoped that this thesis will provide a guide work towards electrification of vehicles from a modular and layout approach.

Key Words:

Scania, Truck, E-Mobility, Internal Combustion Engine, Electrification, Electric Truck, Modularity, Modules, Relations, Interfaces, Modular Toolbox, User Factors, Layout, Powertrain, Battery, Power Electronics, Charging Interface, Cooling, Temperature Control, Power Steering, Suspension, Brakes, PTO, Wheel Configurations, Ground Clearance, Axle Distance, Frame.

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Sten Lundgren – RTC, Brakes
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David Nilebo – Development Engineer, Insplorion
Staffan Sjöström – R, Modularization
Göran Svensson – YDMP, User Factor Study
Linus Ährlig – BRVD, Concept Vehicles

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Abbreviations

RTMX – Truck Layouts and Concepts Department at Scania

ICE – Internal Combustion Engine

EV – Electric Vehicles

CAD – Computer Aided Design

GTW – Gross Train Weight

PP – Propulsion Power

ES – Energy Storage

TP – Transfer Power

DC – Direct Current

AC – Alternating Current

SoC – State of Charge

DoD – Depth of Discharge

AC – Air Conditioner

CD – Central Drive

E-Axle – Electric Axle

NVH – Noise, Vibration and Harshness

DCC – Direct Current Converter

Xbox – Junction Box

BSU – Battery Slave Unit

BMU – Battery Slave Unit

TCS – Temperature Control System

EPS – Electric Power Steering

EHS – Electro Hydraulic Steering

EAS – Electric Assisted Steering

EST – Electrohydraulic Tag axle Steering

EMB – Electro Mechanical Brakes

E-Highway – Electric Highway

HPS – Hydro Pneumatic Suspension

E-Suspension – Electric Suspension

APS – Air Processing System

PTO – Power Take Off

E-PTO – Electric PTO

CCU – Contactor Control Unit

VCA – Voltage Class A (< 60V)

VCB – Voltage Class B (≥ 60V)

AD – Axle Distance

GC – Ground Clearance

BP – Battery Packs

IVD – Increased Vehicle Dimensions

1. Introduction

1.1. Background

The transport industry is facing an extensive technological shift to meet future emission requirements. The intention is to radically reduce CO_2 emissions and to work towards reaching a fossil free society. To accomplish this, majority of the transport industry is switching towards electricity from renewable electricity sources to power their vehicles. To remain competitive on the market, meet future requirements and to lead the development towards a sustainable future, Scania as one of the leading players in the field of heavy vehicles and engines for industrial and marine usage, is also working towards electrification of their vehicles.

However, since the development and research in the field is still in the initial phases, a vast analysis of possible vehicle designs becomes necessary. Therefore, Scania has decided to investigate how the future fully electrified trucks will fit into their already existing truck design. Since Scania uses a modular approach when it comes to designing their vehicles, the electrification analysis must keep the modular approach in mind when performing this analysis. This means that new and fully electrified modules will be added and some of the existing modules will be modified to fulfill the electric needs of the future Scania Modular Toolbox to remain flexible for customer needs and at the same time meet future requirements.

1.2. Purpose

The purpose of this master thesis is thus to analyze which modules are necessary to achieve a fully electrified truck, to analyze the relations between these modules and to propose conceptual layouts of the electric truck to achieve a functional design.

It must also be evaluated which necessary functions are lost when switching from a combustion engine to a fully electrified propulsion and to supplement this with propositional additional solutions.

1.3. Objectives

1. What modules or components need to be removed, replaced or added to the Modular toolbox while transitioning from an ICE powered truck to a fully electrified truck?
2. How will these modules affect the relations with the modules surrounding it?
3. How will these modules fit in the vehicle layout on a holistic level?
4. How much space would these modules occupy on the vehicle?
5. Propose strategic vehicle layouts.

1.4. Limitations

The analysis of the electrified trucks must be done from a modular perspective to ensure compatibility with Scania's modular approach. The current strategic interfaces must be followed to maintain the available space for other components in the truck and to allow future independent replaceability of components. This will also allow Scania to continue to work with their development approach regarding continuous improvements of trucks in minor steps. This master thesis is limited to using electric motor and Li-ion batteries for the purpose of electrification instead of focusing on other alternatives such as fuel cells. Further, European legal requirements, such as outer dimensions and weight of the vehicle, must also be followed to ensure the possibility of reaching the European market. The reason for limiting to only the European market in this master thesis is to ensure that the work can be accomplished in the limited time for the thesis. While deciding on the size of the energy storage for the electric vehicles, legal requirements such as the maximum hours the driver can drive in a day and the results of the user factor study done by Scania for electric vehicles needs to be considered. Additionally, Scania's other products such as buses and separate engines will not be investigated in this master thesis to limit the focus on electrification of trucks. Finally, it should also be strived to allow the truck to be equipped with any mixture of performance steps to maximize the utilization of the modular toolbox.

1.5. Method

The thesis work is divided into three major steps, Pre-study, Component analysis and Vehicle layout proposal. Planning of the thesis work was done using a Gantt chart in order to show the workload sharing, number of hours spent and the breakdown of the overall thesis structure.

Pre-study involves literature study and interviews to understand the basics of how trucks work, the modular system of Scania, vehicle layout of trucks and an in depth study about powertrains of trucks and electric vehicles to understand the differences between ICE engines and electric vehicles which will assist in the next two steps of the thesis work. Literature study will be done using Scania and Chalmers web database while also using the libraries on both premises, along with research articles and reliable online sources. Interviews will be conducted with experts in the field of trucks and electric vehicles at Scania, Chalmers and any other relevant institutes.

After the Pre-study, component analysis was done through benchmarking, literature review on recent technological developments, conducting interviews with experts and brainstorming. All the alternative solutions were evaluated to find the best solution through pro and con analysis and through elimination. While doing the component analysis design for modularity was followed to ensure that modular approach is preserved at Scania. Additionally, design for environment is kept in mind while choosing the best solution among all the available alternative solutions. PowerPoint was used to model the module relations. Layout analysis was done with the help of rough sketches for preliminary analysis followed by models in PowerPoint and in the end with the help of CAD models in Catia V5.

2. Pre-Study

A Pre-study was done to gain a deeper understanding of various related topics such as Scania's trucks, modularization, user factors, Internal Combustion Engine (ICE) vehicles and electric vehicles.

2.1. Scania

Scania CV AB is one of the largest heavy vehicle manufacturers in the world. They are in a transition from being a supplier of trucks, buses and engines to a provider of complete transport solutions to the heavy vehicle needs of the world. Scania has been known to produce higher performing vehicles with low operating costs, longer service lives and higher payloads.

Scania prides in tailoring their vehicles to satisfy customer's specific transport requirements. Few important customer requirements are gross truck weight, speed, type of goods, topography, climate, etc.

In order to satisfy the vast needs of their customer base, Scania divided their truck program into four main segments which are distribution, long distance haulage, construction and special-purpose vehicles. Within these segments, Scania offers tractors and rigid trucks with varying axle distances, axle configurations, chassis heights, suspensions etc.

Distribution trucks are often used for shorter distances and frequent pickups and deliveries. Due to this, they are typically ergonomically designed to allow easy entry and exit from the vehicle. They are also designed to have a smaller turning radius to allow the driver to operate the vehicle in space limited areas.

Long distance haulage is typically defined by long distances traveled over a longer period, putting much focus on weight and fuel optimization along with driver comfort. Due to this, larger cabs are typically used to increase comfort and offer resting possibilities to the drivers. A tractor equipped with semi-trailers is common for this market segment.

Construction vehicles are typically operated in varying terrain and tough conditions. It thus becomes important to design these vehicles for good robustness, mobility, load capacity and operational reliability.

Special-purpose vehicles are highly customized for certain applications. Some of these include firetrucks, road sweepers, garbage collection, defense vehicles, etc. (Scania, 2019).

The trucks mainly consist of three systems which are the cab, chassis and powertrain. The cab is an enclosed environment from where the driver operates the vehicle. Here majority of the controls for the truck are located. The cab is usually equipped with a climate control system to keep a comfortable working environment for the driver. The cab also has its own suspension between the chassis and the cab to keep the driver comfortable on uneven driving terrain. Since the cab is located above the engine, the cab has a tilt function to allow the user to easily access the engine and other related components in terms of maintenance. The chassis has several functions on a truck. It is comprised of many components one of which is the frame which holds all the chassis components together and has heavy load bearing properties to allow the truck to carry heavy loads. Also, the chassis is equipped with suspension, brakes and wheels to ensure safe transportation while the truck is moving. The powertrain on the truck contains all propulsion related components which allows the truck to be propelled forward. This system usually consists of an engine, transmission, etc. Based on the requirement, transmission can be equipped with a power take off either on the engine or transmission which allows the user to power their desired equipment (Scania, 2019).

2.2. Modularization

Baldwin (1997) defines modularity as independently developing small building blocks or subsystems and combining these to create complex products. One of the greatest benefits with this approach is that it gives great flexibility in the development phase, allowing different departments of companies to only focus on their responsible module. This helps to boost the rate of innovation by allowing each department to solely focus on a module and thereby analyze deeper into its inner workings. Visible design rules are specified before developing the modules to ensure that the combined modules work well together. Visible design rules consist of three categories: architecture, interfaces and standards. The architecture specifies the functions of each module and which modules will be part of the system. Interfaces specify how the different modules will interact with each other. Finally, standards are used to examine how well a module complies with the specified design rules. This is also used to compare how well modules compare relative to each other.

However, there are some drawbacks related to modularity which must be kept in mind. According to Baldwin (1997), it is mentioned that one of the biggest drawbacks is the increased complexity of designing the products. This is because a greater understanding of the inner workings of the product is required before the design rules can be specified. Another risk mentioned by Baldwin (1997) is that problems with the modularization often appear first when the modules are connected and are not performing well as a whole.

2.2.1. Modularization at Scania

Modularity has been a constant part of Scania since 1930s. It is ingrained in the walls of Scania. Scania uses modularity as a tool to provide superior transport solutions to varying market needs while keeping the lowest possible cost to the customer. Scania believes that modularity starts and ends with the customer which is why they put utmost importance on understanding each customer's specific needs. At Scania, modularity is achieved using certain methods and principles. Principles determine the common way of thinking while the methods are the common way of working to get the results. Results can be introducing the right product at right time, late variant definition in production and development so that the user can make late changes which is profitable to both Scania and the customer (YDMM, 2018).

According to Scania (2010), there are three main modularization principles which Scania follows to ensure a common way of working throughout the company. One of these principles is to use standardized interfaces. This will in turn allow easy interdependent changing of components without the need of adjustments. The next principle is to create well balanced performance steps. There should be an appropriate amount of performance steps which are all dimensioned to meet different customer needs. Creating an excess of or unbalanced performance steps is unnecessary and thereby undesirable. Finally, the last principle is to use identical solutions for the same customer need. It is not efficient for a company to redevelop the same solution. Using the same solution as much as possible will also help to makes it easier to maintain warehouse levels of spare parts.

Scania believes these three methods to be essential for modularization: operational factors and recommendations, variant coded product structure and variant part tracking. Operational factors such as topography, road condition, traffic condition and climate provide the essential knowledge in order to develop the right vehicle and to avoid making changes just for the sake of technology. Variant coded product structure is an open and dynamic product structure that is governed only by the factors that determine the technical properties of components. This provides Scania with the opportunity to optimize and tailor the final solution to customers by keeping different combinations of design solutions available late in design work. Variant part tracking is a visual support that helps keep track of number of parts compared to number of variants. This will help reduce the number of unique components which helps reduce the cost (Scania, 2010).

At Scania, all the possible solutions for a customer need is evaluated from a strategical perspective against factors such as price, investment, knowledge etc. Components are standardized only if all the customers have a need for those, otherwise Scania strives for having a combination of components that meets the customer needs in a balanced way and avoid over dimensioning a component to create a 'one size fits all' solution (Sjöström, 2019).

Having a modular approach with standard interfaces help Scania optimize the modules or components since this approach gives full freedom to the component owners to create the best possible version of a component if the interfaces are followed. This in turn help Scania provide customers with fully optimized trucks.

Modularity enables Scania to provide their customers with the best products by combining components in numerous permutations and combinations. It also helps in reducing the number of unique components between two different products. For example, left hand drive can be converted to right hand drive with very few changes of components (YDMM, 2018).

The use of a modular system allows Scania to continuously develop new solutions in a shorter time since they put more focus on developing modules instead of entire integrated products. This means that the size of investments and reservation of resources is decreased which results in more flexibility for the company. This also results in faster time to market. Scania is also able to offer a wide range of products to the customers as fast as possible while keeping the number of unique parts and components to a minimum. This is because many of the existing solutions can easily be reused for many of the products. The modular approach also allows Scania to tailor their products to a high degree for customer needs. This is highly desirable for the customers since most of them have a wide spread of needs.

2.2.1.1. Terminology at Scania

The term 'Module' is not used at Scania since it needs to be defined every time it is used which makes it hard to pass the information on to all the employees of Scania, instead words such as component, performance series and performance steps are used. Some of the important terms used for modularity at Scania are as follows (Lange, 2019):

User Factor:
At Scania, modularity starts and ends with the user therefore user factors are given high importance. A user factor is an independent condition that describes a part of the transport system such as driver comfort, topography, road condition, traffic condition, emission requirements etc.

Performance Demand:
The unique quantitative performance demand of a specific operation or a type of customer

Performance Series:
Performance series denotes a similar meaning as a module. At Scania, it was used to be known as component series, which denotes the component or an independent functionality that satisfies a performance demand such as propulsion power, energy storage, steering etc. Performance series covers not only specific components but also other performance demand such as service.

Performance Step:
Each performance series is divided into well-balanced steps that either provides alternative solutions for a performance demand or different positions of a certain component or varying performance levels.

Interface:
An interface enables the interdependent combinations between performance series.

Solution:
A solution is a combination of performance steps from different performance series that fulfill the customer needs and demands.

Bygglådan:
Also known as modular toolbox which is a representation of all the performance series with standardized interfaces.

2.2.2. Types of Interfaces at Scania

The reason for having an interface vary from legal demands, standards, and customer needs to internal strategies of Scania. Having these interfaces help Scania achieve the structure of vehicle composition early in the design process, define available space for components and provide support for designers within Scania and to external partners (RTMX, 2018).

As mentioned above, Scania uses standardized interfaces with performance steps to define available space for components thus ensuring easy independent changing of components. There are thus three types of interfaces which are contact, spatial and information interfaces. The contact interface is how the components will be mechanically connected to each other. An example of contact interfaces is screw joints. A spatial interface specifies the space limitations between components to increase robustness in the design. They are mainly used for strategical purposes to allow varying dimensions of components without creating chain reactions or negatively affecting other components in the truck. This problem might for example occur when switching over to a higher performance step which results in slightly larger component dimensions. Finally, the information interface is used wherever there is an exchange of data (Scania, 2010).

Standardized interfaces can be both legal and strategic interfaces. Legal such as chassis width which determines the maximum possible width of the truck whereas strategic such as size and position of each module or component. Most components of the truck have one dedicated position. Apart from these there are also project interfaces that are specific to a project and can have an extreme truck condition. Another interesting interface used by Scania is the 300 mm interval interface that is aimed at reducing number of unique components. Components that are added on the side of the truck can take up one or more of these 300 mm intervals where within this interval, movement and tolerance should also be accounted for (Åkeson, 2017).

Other interfaces that are useful for the project are ground clearance, trailer interface, engine tunnel, boarding step, side floor, C14 cab suspension, supporting leg and frame holes. Ground clearance is measured between the top of the frame and the maximum allowed distance to the bottom of a component. It is aimed at keeping the components within certain distance from frame top to ensure that the components won't get damaged due to the irregularities on the road. Scania offers trucks with two ground clearances, 'low' and 'high.

Trailer interface denotes the space occupied by the trailer that can be attached to the truck, this interface occupies the space behind the cab and above the frame. Therefore, while placing components on the truck, it is to be ensured that the components are kept outside of this interface. Engine tunnel interface is derived from the combustion engine that is kept under the cabin in the front of the truck. This interface provides the boundary for the engine which means that the engine should be kept within this interface.

Boarding step interface denotes the various boarding steps to the cabin that are offered by Scania. This interface defines the boundaries for these steps and while placing components in the front of the truck it is to be ensured that the components doesn't interfere with this interface. Similarly, side floor denotes the boundary of the side floor of the cabin and provides a boundary conditions for components placed under the cabin.

Cabin needs to be suspended in order to provide driving comfort to the driver irrespective of the road conditions. Scania provides various cabins that differ in size and C14 is the smallest cabin that is offered at Scania, therefore C14 cabin suspension interface provides a boundary condition for the components that are kept in the engine tunnel region. It is to be ensured that components such as engine are kept within this interface and engine tunnel interface. By following these interfaces, it can be ensured that the components placed in the engine tunnel can always have this position for them irrespective of the type of cabin or the truck.

Supporting leg interface is in relation to the truck that are used as cranes, for these kinds of trucks, supporting leg is used to support the crane while it is being used to lift and move heavy objects. This interface occupies the same space as the boarding steps that are kept behind the front axle that allows access to crew cabin or catwalk behind the cabin. Frame holes interface denotes the modular hole pattern used at Scania where frame is filled with holes with certain gap between them. These holes are used to simply the process of installation of components on to the frame and to support bodybuilders in the effective packaging of components (Åkeson, 2017).

2.2.3. Scania Modular Toolbox

This is the collection of all the components which are used at Scania according to Scania (2010). The aim is to reuse the existing solutions as much as possible through the standardized interfaces. Optimal implementation of the Scania Modular Toolbox will result in many product varieties with a limited number of components. The toolbox is modeled in a way to enable the composition of a balanced product that meets any customer's specific needs. This toolbox will be adapted over time to allow the changes for electric vehicles and will allow more combinations.

Components are divided into various performance series and each performance series will have multiple performance steps based on the requirement of users. Performance steps can be alternative ways of realizing a particular need or different performance on an already realized solution. Sjöström (2019) states that needs of the customer and market should be the basis for introducing new performance steps. For example, engine for an ICE powered truck can be realized as a performance series while the three engine variants offered by Scania, straight 5, straight 6 and V8 are the performance steps. A sample of the Scania's modular toolbox can be seen in the *Figure 2.1* below.

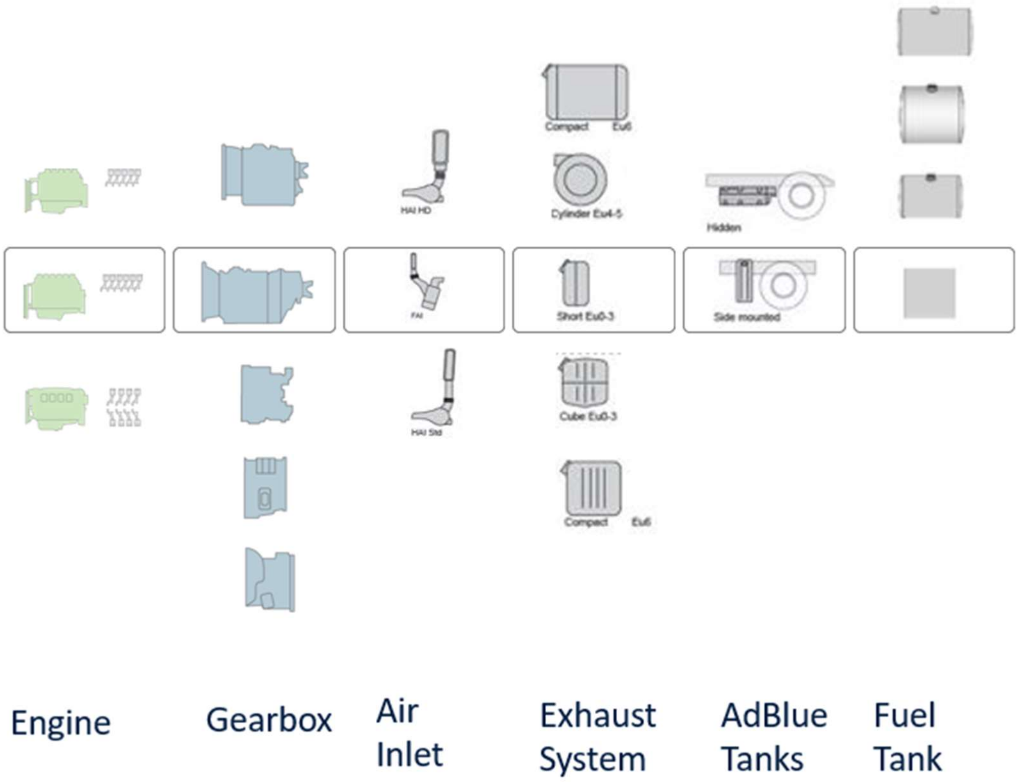


Figure 2.1: Sample of Scania's Modular Toolbox

2.3. User Factors

Since Scania offers the possibility to tailor their products according to the customers' needs it then becomes important to analyze how the customers wants to use their products to ensure optimal configuration for their intended use. Therefore, user factors play an important role while designing a truck, be it a diesel-powered truck or an electric truck.

2.3.1. Basic Factors

Factors used to determine the performance of a truck are numerous; they range from operational factors to aesthetic factors. Some of the typical factors used at Scania are discussed below.

Topography:
Topography affects the product specification of powertrain, fuel consumption and performance of turbo compressor (YDMM, 2016).

Road Condition:
Road condition determines the road roughness that affects service life of axle, suspension, frame and body, rolling resistance that affects fuel economy and service life and sinuosity that affects tyre and chassis strength (YDMM, 2016).

Traffic Condition:
Speed of the vehicle and its variability over time affects the life of driveline and fuel consumption. Cruising speed affects air resistance and fuel consumption. Annual distance and annual operation require maintenance and idling without power take-off affects fuel consumption and wear of parts (YDMM, 2016).

Payload Capacity
This specifies how much cargo or how heavy equipment the truck can carry in terms of weight. This needs to be kept in mind when designing the vehicles to ensure that the customers can carry their cargo without exceeding legal regulation (Scania, 2010).

Fuel Efficiency
How much fuel does the truck consume during usage? For long distance haulage this is an important factor since it can greatly impact the costs for the customers (Scania, 2010).

Reliability
How often do failures occur? How often does the machine break and require immediate maintenance before it can be used again? Machinery used in off-road terrain or similar hard to reach areas are extra sensitive to this (Scania, 2010).

Availability
How often is the truck useable? How often do you need to refuel or charge batteries? For distribution (shorter distances) the trucks can be designed with smaller fuel tanks or batteries. For long distance haulage it becomes important for the customer to not have to stop to refuel or charge batteries since it will limit their ability to perform their intended task (Scania, 2010).

2.3.2. User factor study

A user factor study was conducted by Scania to understand the varying conditions under which trucks are being operated in. These factors include but not limited to Gross Train Weight (GTW), topography, rolling resistance, grade of slope and cruising speed. The findings of the study were used to calculate the propulsion power, energy storage and transfer power of the trucks for different conditions. All the different values were grouped together to determine various performance steps on propulsion power, energy storage and transfer power.

Propulsion power (PP) is the power at the wheel, this is lower than the component power and does not include losses in the drive train. Energy storage (ES) is the electrical energy at the DC link, it is lower than battery capacity and does not include losses and Depth of Discharge (DOD). Transfer power (TP) is the power needed to charge the batteries in the time available without losses (Svensson, 2019).

The performance steps of PP, ES and TP that are derived from the study can be used as a basis to determine the number of batteries needed to satisfy the customer demand.

2.4. ICE Powertrain

Woodford (2018) explains that typical diesel engines work by burning diesel in a four-stroke process inside the cylinders. To deliver the fuel to the engine, the truck must be equipped with a fuel system which typically consists of fuel tanks, fuel lines, fuel filters as well as fuel pumps. Since the burning process in the engine requires air, the truck must also be equipped with an air intake and an air filter. The emissions from the burning process in the cylinders are carried away and handled by the exhaust system. To fulfill legal requirements regarding emissions, the exhaust system is also supplemented with a treatment system. However, due to the heat buildup in the engine which is caused by friction and heat from the combustion it becomes necessary to supplement the engine with a cooling system (Bluestar, 2018). The main purpose of the cooling system is to keep the engine at an ideal working temperature, regardless of the ambient temperature.

The cooling system mainly consist of radiators, fan and pumps and is connected to the components which require cooling. The radiators exchange heat between the cooling system and the ambient air while the pumps help to move the coolant media around in the system. The coolant media transfers the heat in the system and is usually a mixture mainly consisting of water and glycol. However, oil can also be used as a coolant media, but it is not as common. The radiators are usually placed in the front of the vehicle to utilize the ram air to increase the airflow through the radiators which helps to increase their effectiveness (Hall, 2019). A radiator fan is placed just behind the radiator that helps increase the air flow around the engine. Since ICE engines also occupies a large amount of space it becomes difficult to place the engine anywhere else except underneath the cab in the front of the truck. Should the engine be placed further backwards on the truck, then there is a risk that it would limit the cargo volume and payload due to the decreased available space and increased load on the rear axles. Due to this, and the fact that the rear axles are typically the driven ones, it becomes necessary to equip the truck with a cardan shaft which connects the transmission to the powered axles. This means that the cardan shaft will occupy a lot of space along the middle of the truck.

Apart from providing the propulsion requirement for the truck, the engine is also used for various auxiliary purposes. The heat by-product from the engine is used to heat the climate system in the cab to keep the driver comfortable. Furthermore, an AC compressor is used in the climate control system of the cab and is directly powered by the engine.

The engine is also used to power the PTO by connecting it to either the transmission or the engine itself. Finally, the engine is used to power the air compressor which stores compressed air in air tanks and can later be used to operate brakes, suspension, etc.

Since the trucks contain many devices which require electrical energy, such as exterior and interior lights, they must be equipped with an alternator to not drain the batteries (Wright, 2018). The alternator is connected to the engine and converts mechanical energy to electrical energy.

2.5. Electrified Powertrain

Electric vehicles (EVs) provide numerous advantages over ICE; they emit zero emissions and close to zero noise. This will help in reducing the noise and air pollution and also helps in using the electric trucks for delivery at night in cities which is forbidden now due to the noise made by ICE trucks (Scania, 2019). Reduction in emissions will help the vehicle manufacturers meet the future government regulations that will be placed on vehicles. Governments across the world have already started placing strong regulations when it comes to emissions in an attempt to reduce climate change. For example, Amsterdam introduced a policy aiming to have zero emission traffic by 2025 (City of Amsterdam, 2018). EVs also provide the opportunity to recuperate the brake energy which will especially benefit the trucks used in urban areas such as distribution trucks which go through lot of start and stops due to traffic.

2.5.1. Background

Electric propulsion systems have been around since as early as 1830s when a Scottish inventor named, Robert Anderson invented an early type of an electric motor and used it to power a small model car. Through the invention of rechargeable batteries and their subsequent improvement in capacity towards the end of 19th century made electric vehicles practical and commercially viable (PBS, 2009). After enjoying a brief success in the beginning of 20th century, electric vehicles took back seat when the discovery of large fuel reserves reduced the gasoline prices and made gas powered vehicles affordable. The dawn of 21st century brought a renewed interest in electric vehicles due to multiple factors such as rise in gas prices, significant developments in Lithium-ion batteries and the growing global awareness to reduce the climate change.

An electric powertrain works by converting the electric energy into mechanical energy. It usually consists of an energy carrier that is the source of the electric energy and an electric machine which is usually an electric motor that provides the vehicle propulsion. The energy carrier is usually an electrostatic or electrochemical energy storage system which can be batteries, super capacitors or fuel cells. The important characteristic of a motor is its power and for a battery it is the energy storage (Guzzella and Sciarretta, 2013).

Electric machines have been part of conventional ICE powered vehicles as starters and alternators. As a starter, an electric machine provides boost to the engine to reach its idle speed and as an alternator it is used to charge the 12/24V batteries (VCA) and to power the electric auxiliary loads. An electric machine can be used in multiple ways in a vehicle, it can be used to convert the electric energy of a battery into mechanical energy to propel the vehicle or it can be used to recharge the batteries by recuperating the mechanical energy of the drive train during regenerative braking. It can also be used to convert mechanical energy of the engine into the electric energy of the batteries, which won't be discussed here due to the absence of an ICE engine in a fully electric vehicle.

An electric machine or motor consists of a rotor and a stator where the rotor is connected to the output shaft on which the motor torque is acting. Motors can be classified into two types, AC (Alternating Current) and DC (Direct Current) motors. These types can be further classified into subsequent types based on their principle of operation.

Batteries are the most prominent energy carriers for electric vehicles. Batteries work as reversible energy storage devices which means they convert chemical energy into electric energy and vice versa. Important parameters of a battery are its nominal capacity (Ah) which fulfills the coveted driving range specification and state of charge (SoC) which shows the remaining capacity of the battery in percentage of its nominal capacity. A battery used in an electric vehicle is desired to have a high specific power (kW/kg) and energy (Wh/kg) along with low initial and replacement costs, long cycle life, high reliability and robustness at wide range of operating conditions. Specific energy takes into account that the whole capacity of the battery cannot be used, instead batteries are used in a specific SoC window with limits for minimum and maximum SoC levels that determines the charging and discharging limits and also the range of the vehicle.

Most commonly used batteries for vehicle applications are lead-acid, nickel-metal hydride, lithium-based, molten salt and metal-air. Due to its high specific energy and power, Lithium ion batteries are being preferred by most of the vehicle manufactures as of now. Batteries can be optimized for maximum specific energy or power usually by varying the thickness of electrode (Guzzella and Sciarretta, 2013).

Batteries are being developed constantly to increase their energy storage capacity therefore the energy demand of batteries for the future should not be based on the capacity of batteries of today.

There are ways of recharging batteries faster if gel batteries are used since recharging a gel battery means refilling the gel, it will be similar to filling Diesel. But this technology is still under development, therefore not part of the analysis.

2.5.2. Electric Energy Storage Alternatives

This master thesis will focus on lithium ion batteries. However, a market study was conducted to get a better understanding of what technologies currently exist and how the market may change in the future due to these technologies.

2.5.2.1.1. Fuel cells

Scania has already taken steps towards it through their development into hybrid and fuel cell powered vehicles. Hybrid vehicles use both electric and diesel-powered engines which helps in reduction of losses and better fuel consumption compared to diesel powered engines. Fuel cells can be realized by converting the ICE of a hybrid vehicle to fuel cell where fuel is converted into current without combustion. They excel over ICE in terms of reduction in emissions, noise, vibration and fuel efficiency but they still require a constant source of fuel and oxygen. They excel over electric vehicles in terms of range and payload capabilities due to the higher specific energy of hydrogen over batteries but it is not seen as an ideal replacement for ICE engines due to lack of infrastructure of hydrogen fuel stations and the many stages involved in production and transport of the fuel that results in its inefficiency over the entire life cycle compared to electricity (Scania, 2019).

Fuel cells provide advantages over fossil fuel in terms of efficiency, reduction in emissions and reduction in noise. Whereas fuel cells have slow reaction rate which leads to low currents and power that is not desired and also hydrogen is not a readily available fuel which results in infrastructure complications since hydrogen filling stations are very few (Dicks &Larminie, 2003).

Using fuel cells provide the advantage of having reduced changes to an ICE truck and they provide higher range compared to using batteries. Fuel cells use Hydrogen as the fuel which has the highest mass energy density among conventional fuels but has lower volumetric density which means it requires more storage facility. Therefore, Hydrogen is liquified in order to store large quantities, however it is still not comparable with fossil fuels. Additionally, Hydrogen has auto ignition temperature which is why it is not safe compared to fossil fuels due to leakage and flammability (Nguyen& Lindström, 2017).

2.5.2.1.2. Carbon Fiber

For electric vehicles, there are more ways of storing electric energy than only through batteries. One of the ways according to Chalmers professor Leif Asp who works with reinforced composites is to use carbon fiber as a storage unit for electricity. He along with his colleagues has discovered that carbon fibers can be used as battery electrodes and thus store energy directly. Carbon fiber is used mostly in applications such as race cars and aircrafts but is limited in its application in consumer vehicles such as cars and trucks due to its high cost, but they provide additional benefits such as reduction in weight and increase in strength and stiffness which is essential for EVs. If an EV is made of carbon fiber, it can be used as a structural battery to store energy along with providing the load bearing function and the reduction in weight achieved can be used to store additional batteries thus increasing the range of the vehicle (Wilde & Folino, 2018).

Asp claims that using carbon fiber in an EV will result in 50% reduction of the vehicle weight which will increase the payload of the customer when used in trucks which is beneficial for Scania. This is achieved by changing the microstructure of carbon fiber thus changing their electrochemical properties. Increasing the electrochemical properties of the fibers result in reduction of the stiffness which is also an essential requirement for vehicles but even with this reduction in stiffness, carbon fibers are still better than steel. Therefore, he concludes that for EVs, this is a worthy tradeoff. Additionally, carbon fibers used as structural batteries are safer than traditional batteries since they would not contain any volatile substances (Wilde & Folino, 2018).

Carbon fibers provide the opportunity to extract electric energy at multiple locations thus providing the strategical advantage of designing the structural batteries to the need. Vibrations and forces experienced by the vehicle can be converted into electric energy and can be stored. Compared to traditional batteries, structural batteries lack in their energy density but are used for multiple purposes at the same time. Additionally, carbon fibers demand a very energy dense manufacturing process which reduces their environmental friendliness therefore it is advised to use renewable sources for manufacturing of carbon fibers. The advantages of using carbon fiber as structural batteries outweigh the disadvantages which is why Air bus is testing this technology in their new vehicles. But the technology is still under development and will take few years before it can be realized on a commercial basis (Asp, 2019).

3. Modular Toolbox Analysis

In this chapter it will be discussed how components are affected by the electrification of the trucks. It will here be stated for electric trucks what is no longer necessary to use, what can be carried over and what new things need to be added and modified. All 3D-models of the components presented below were retrieved from Scania's existing CAD database. If many models were available, then the newer and larger models were used to better represent the necessary reserved volume for the components. The information required to perform this analysis was obtained by interviewing various people at Scania who were versed in each respective area of the truck.

Since many components on the truck will be altered due to the electrification it also means that Scania will need to alter their modular toolbox. As mentioned earlier, instead of having one toolbox, the toolbox will instead be grouped into three categories. Each of these of these will represent performance series which are either ICE specific, shared on both ICE and electric or electric specific performance series. An example of the ICE specific performance series is presented below and shows typical performance series which will only be offered to ICE vehicles. It can here be seen that these performance series are all linked to the ICE engine. This will similarly be done for both shared performance series as well as electric specific performance series.

3.1. ICE Specific Performance Series and Steps

Since electric trucks do not use ICE then it is also no longer necessary to use supporting components for the ICE on the electric truck such as air inlet system, alternator, aftertreatment for the exhaust system, fuel filters, fuel pumps, fuel lines, fuel tanks, etc. However, when the engine is removed then some necessary supporting systems will also lose their source of power since the engine currently works as the main source of power for many chassis and powertrain components on the truck. This includes power to the air compressor for the compressed air circuit, power to the radiator fan, power to the water pumps in the cooling circuit, power to the AC compressor, power to the hydraulic pump for the power steering, etc. These systems will thus be affected by the electrification and will need new sources of power. Alternative solutions will be discussed further down below. An example of the ICE specific performance series can be seen below.

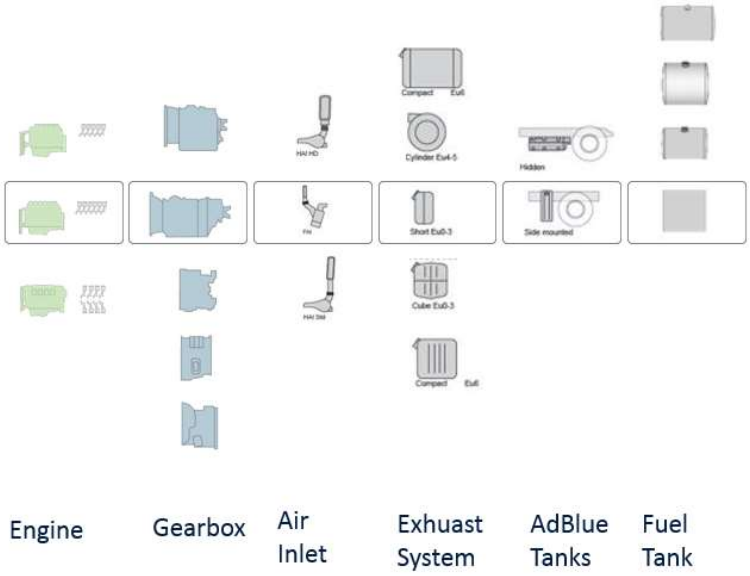


Figure 3.1 – Example of ICE Modular Toolbox

3.2. Unaffected Performance Series

Here the performance series which are not affected by the electrification will be mentioned. These will be carried over and re-used for electric trucks. An example is presented below of how the shared modular toolbox might look in the future. The components here will be possible to use on both ICE and electric vehicles since they are not affected by the electrification. Some relevant shared performance series will be further described below.

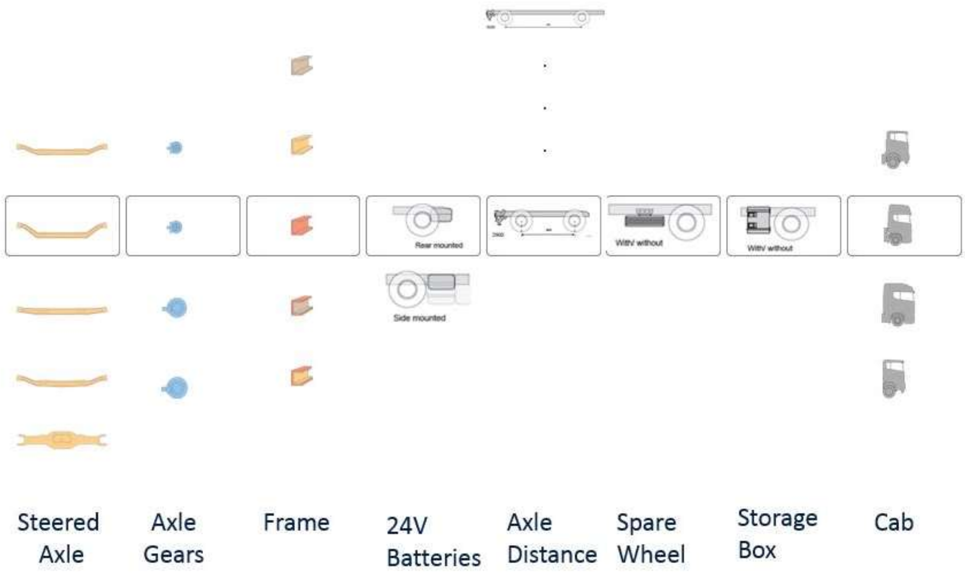


Figure 3.2 – Example of Shared Modular Toolbox

3.2.1. Frame

The frame is the central structure of the truck which helps with load bearing properties and allows various components to be mounted to it by using brackets. Components that need to be removed for servicing are mounted with fitted bolts whereas engine and power transmission are mounted on rubber pads to suppress vibrations and to provide corrosion resistance (Scania, 2019).

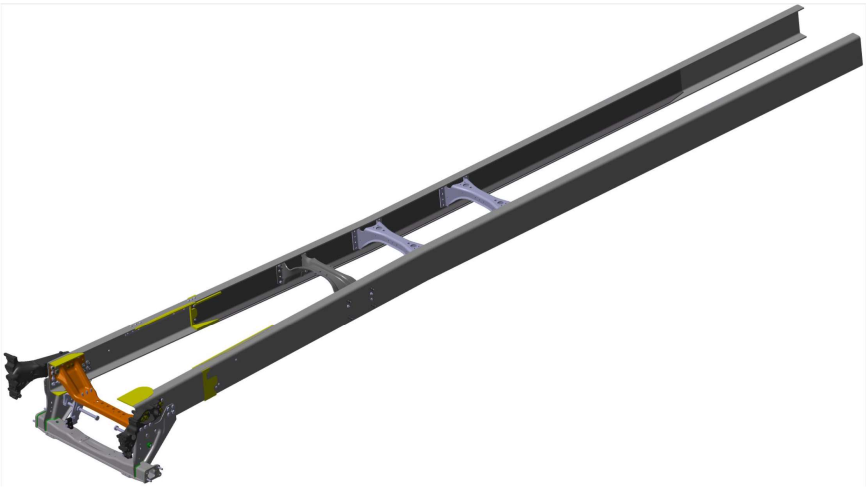


Figure 3.3 – Example of Frame

3.2.2. Cab

Scania offers wide range of cabs with varying lengths and roof heights to fit varying customer needs. Most of the cabs offered by Scania can be divided into 5 types: L, P, G, R and S series (Scania, 2019). L series cabs are lowest and smallest cabs that makes them suitable for construction and multi stop distribution. G series cabs or medium cabs are spacious and allows storage compartments within the cab and are used in long haulage and construction. R series cab or high cabs that offer the utmost comfort to the user allowing him to move around freely in the cab. These are the most spacious cabs and can be used for varying applications based on customer needs. R series sleeper cab is most suitable for long haulage whereas the day cab is suitable for construction and distribution. Cabs of all three types can be converted to sleeper and day cabs based on requirement and can be fitted with additional seats to allow more passengers to ride along in the cab.

Figure 3.4 – Scania R 500 6x4 grain transport (Scania CV AB, 2018)

Figure 3.5 – Cab interior of a Scania G-series XT (Scania CV AB, 2017)

3.2.3. Wheel Configuration

Scania offers performance steps on wheel configurations ranging from 4 wheel to 14-wheel drive based on customer requirement. Performance steps are also offered on number of driven and steered wheels. In *Figure 3.6* the most common wheel configurations offered by Scania can be seen.

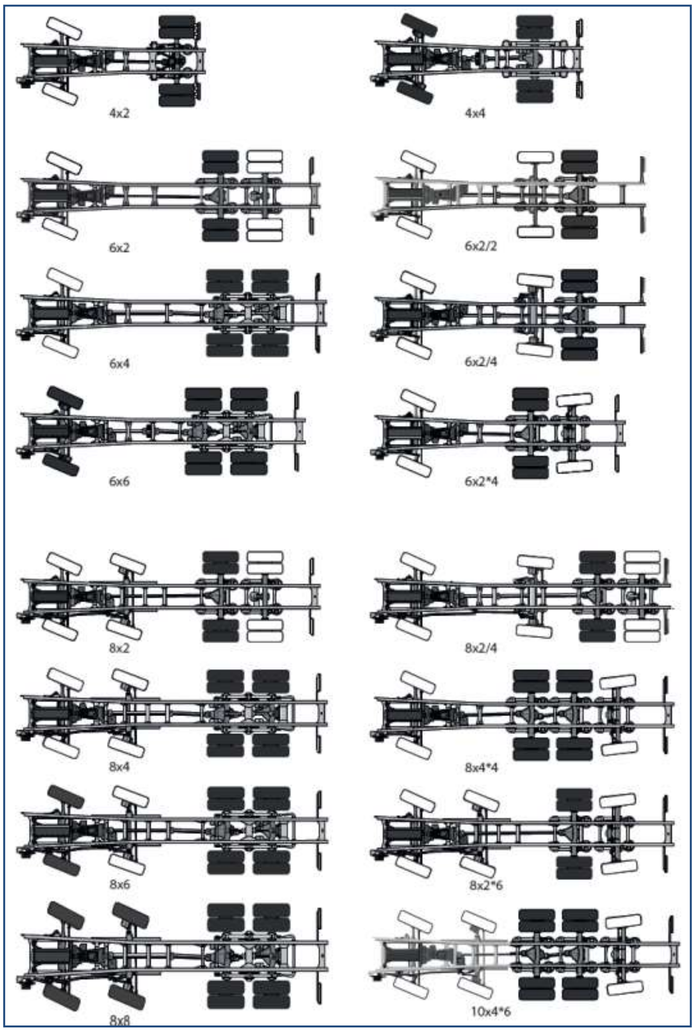


Figure 3.6 – Typical Truck Configurations

The black wheels represent driven wheels while the white wheels represent non-driven wheels, whereas straight wheels represent non steered wheels and turned wheels represent steered wheels (Scania, 2019). As we can see form the picture, front axles in all the configurations are steered. Double wheels placed next to each other on the same side of an axle counts as one wheel. The wheels on a truck are represented using a configuration code AxB, where A represents the number of wheels and B represents the number of driven wheels. When a truck has more than 2 steered wheels, then the code is extended by using either a '*' or a '/' to show the location of the additional steered axle. '*' is used when the additional steered axles are added behind the rear most driven axle and '/' is used when they are added in front of the rear driven axles. For example, 6x2*4 represents 6 wheels on the truck where 2 are driven and 4 are steered and the extra steered axle is added behind the rear driven axle.

3.3. Modified and Added Performance Series

Here the performance series which are affected by the electrification are analyzed. The function of these performance series will be stated, how they work today, alternative solutions as well as placement of these new solutions on the layout.

3.3.1. Propulsion

The propulsion is today comprised of an engine and transmission and is used to accelerate the truck when it is desired by the driver. The current engines at Scania are all ICE (Scania, 2019). Transmission is used to transmit the power from the engine to the wheels using a gearbox, clutch, propeller shafts and driven rear axles. The transmission offers users the opportunity to change the gear ratio either manually or automatically to improve fuel efficiency. A clutch is used for manual transmissions to transmit power from engine to the gearbox. It provides smooth transition between gears, removes jerking and damps the torsional vibration. Similarly, a torque converter is used for automatic transmission to connect the engine and the transmission. A propeller shaft is also used to transmit the power from the gearbox to the driven axles.

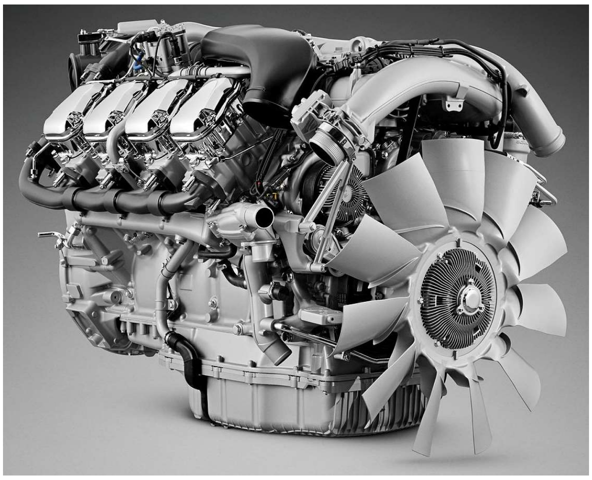


Figure 3.7 – DC16 Euro 6 V8 diesel (Scania CV AB, 2017)

3.3.1.1. Alternative Solutions

EPowertrain concepts are currently under development to provide vehicles with electric powered propulsion to meet future emission regulations. There are different ePowertrain concepts that are available on the market and Scania is also developing their own ePowertrain concepts with different performance steps to satisfy the needs of their customers. Each concept has its own advantages and disadvantages which makes them suitable for certain applications over others. These concepts are further described below.

3.3.1.1.1. Central Drive (CD)

This concept places the motor and transmission between the frame and partly underneath it. It uses a propeller shaft and conventional driven axle which makes it easy to implement with the current toolbox. CD also gives mechanical robustness and durability while being less efficient compared to other alternatives due to the many moving mechanical parts. CD also provides an option of directly powering the PTO and other auxiliary equipment. Since the CD is connected to the rear axle and uses a propeller shaft it must be placed in the position shown in *Figure 3.9*. However, there is a possibility to slightly alter the length of the propeller shaft, making it possible to shift the position along the truck.

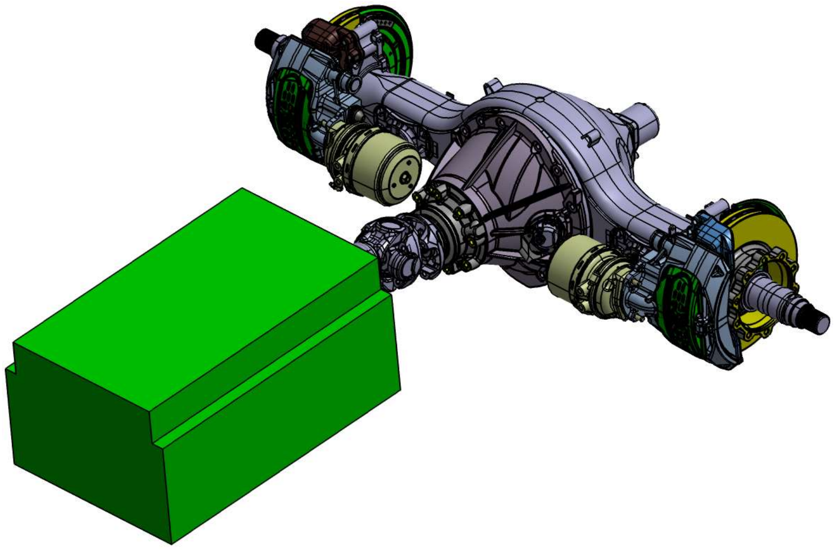


Figure 3.8 – Central Drive and Rear Axle

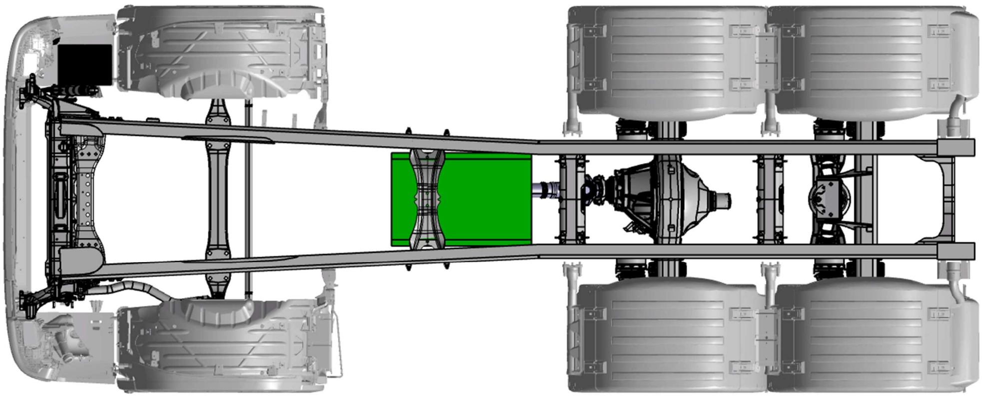


Figure 3.9 – Central Drive Position on Truck

3.3.1.1.2. Rear Drive (RD)

The RD is similar to the CD with the exception that the transmission and motor are mounted closer to the driven axle and is therefore more compact (Scania, 2019). It similarly uses drive shafts to deliver the power to the wheels. This is a type of near wheel drive system which is placed close to the driven axle position. The RD offers greater benefits in comparison to the CD but has a longer time to market due to the higher amount of necessary development work. It is as of now in Scania believed that the RD might be implemented further in the future in comparison to the other presented alternatives.

3.3.1.1.3. E-Axle

The E-Axle integrates the motor and transmission into the driven axle. This is a type of near wheel drive system which is therefore compact in comparison to the CD. This can help to increase the amount of free space on the truck, which will make it easier to place other components. The E-Axle does have higher NVH (Noise, Vibration and Harshness) compared to central drive. Since it is not mounted to the suspended chassis it thereby increases the unsprung mass on the truck which results in lower robustness and durability compared to other alternatives which are mounted to the suspended areas of the truck. Since the E-axle is integrated together with a rear axle it only has one possible position, which is directly where the driven axle is. This is shown below in Figure 3.11.

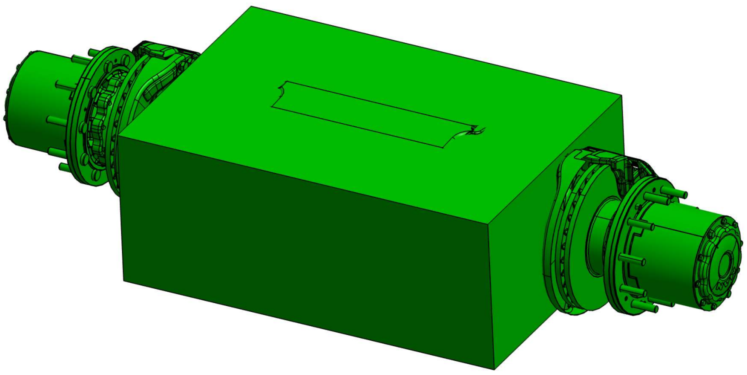


Figure 3.10 – E-Axle

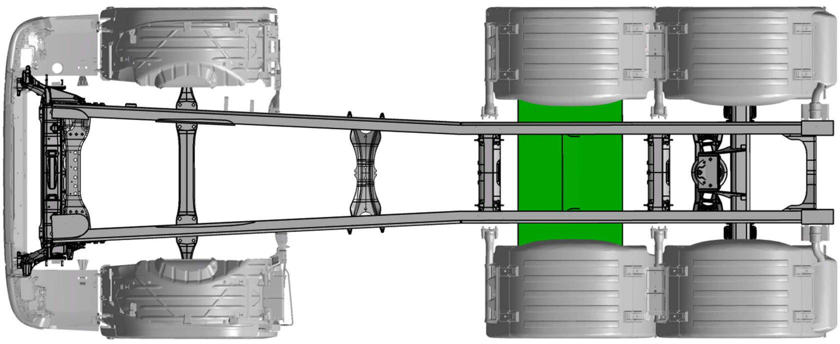


Figure 3.11 – E-Axle Position on Truck

3.3.1.1.4. Wheel Selective Drive

Wheel selective drive provides similar pros and cons as E-Axle with the additional advantage of being able to independently power each driven wheel. It also offers higher power performance at a higher cost. This solution would be placed at the same position as the driven axle.

Figure 3.12 – Wheel Selective Drive (BPW: Ausblick auf zukünftige elektrifizierte Lösungen, n.d.)

3.3.1.1.5. Wheel Hub Drive

The Wheel Hub Drive works similarly to the Wheel Selective Drive mentioned above, with the exception that the motors to the wheels have been moved outwards from the center to clear space for placing other components. This unit would also be placed in the same position as the driven axle. The suspension shown below is not part of the solution but helps to visualize how it would look when placed next to other components on the truck.

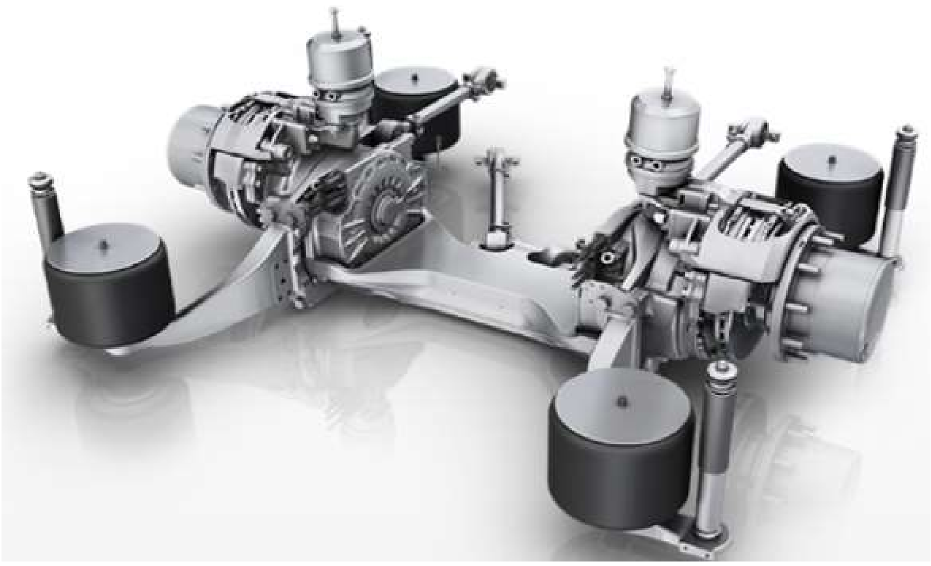


Figure 3.13 – Wheel Hub Drive (ZF Friedrichshafen AG, n.d.)

3.3.1.2. Chosen Alternatives

Due to the limited time of this master thesis it was not possible to perform a full comparison of all the presented alternatives. Since the E-Axle also represent the necessary space for both Wheel Selective Drive as well as Wheel Hub drive it means that similar benefits can be assumed for both. Additionally, since the CD and E-Axle are currently under development at Scania it means that more information regarding this technology could be obtained, which includes 3D CAD models that could be used for the layout analysis. Therefore, it was decided to focus on the CD and E-Axle for this master thesis since it mainly has a layout perspective on the electrification and will not focus on aspects such maximum power, etc. It should also be noted that it is proposed to use the name propulsion for this performance series since it will not only include engines to propel the truck forward, but motors as well. An example of how the propulsion performance series may look in the modular toolbox can be seen in *Figure 3.14* below.

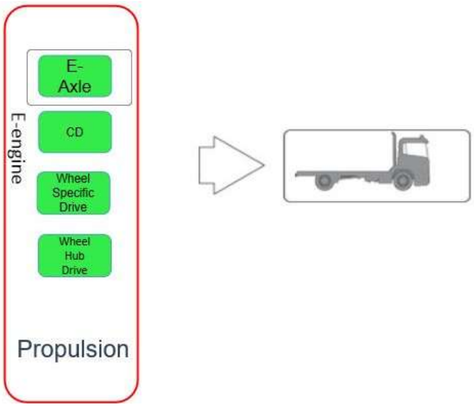


Figure 3.14 – Example of Propulsion in the Modular Toolbox

3.3.2. Energy Storage

3.3.2.1. How it Currently Works at Scania

Scania currently uses diesel and gas as the main types of fuels for their trucks. They offer different performance steps on how to store these on the trucks through size and location of the fuel tanks to satisfy various customer needs in terms of range before refueling is necessary.

3.3.2.2. Batteries

If the trucks are electrified, then diesel and gas fuels can no longer be used as a source of energy. Therefore, it becomes essential to look into other alternatives. All the different energy storage options have their own advantages and disadvantages and they provide multiple ways of moving forward in electrification. However, this master thesis will mainly focus on Li-ion batteries due to its predefined objectives. Batteries provide less energy density compared to fuels such as diesel and petrol which is why for the same range requirement, more volume and weight is needed for batteries compared to the conventional fuel. This provides certain challenges in trucking industry where the customers profit is affected by the payload. Therefore, increasing the weight is not beneficial for the customer and the volume increase will make it difficult to fit other necessary parts on the truck.

Since not only conventional fuel like diesel and gas will be used to power the vehicles, but also electricity from batteries and perhaps more sources, it is proposed to use the name energy storage for this performance series. From interviewing Sjöström (2019) it was also found that while designing energy storage options for electric vehicles, it is essential to keep the Scania modularity in mind.

Instead of standardizing the energy storage by having a one solution fits all approach, there is a need to be more flexible by having various performance steps on the energy storage. Also, adding many small batteries will increase the amount of cables and piping and will thereby occupy more space and increase installation costs. Therefore, it is beneficial to strive towards having bigger batteries that can hold large amount of electrical energy to reduce the number of batteries. The performance steps for batteries will be in terms of various sizes and shapes of the batteries, similar to the existing performance steps of fuel tanks. An example of how the energy storage performance series may look in the modular toolbox can be seen in *Figure 3.15* below.

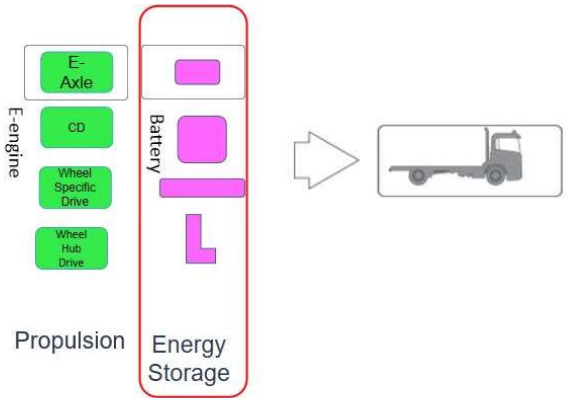


Figure 3.15 – Example of Energy Storage in the Modular Toolbox

The Li-ion batteries which Scania is planning to implement in the future consists of series connecting a certain amount of battery modules and placing these inside a box to form one battery pack. The reason for series connecting modules is to reach a certain voltage which is required for the propulsion components (Cederlöf, 2019). Since these batteries generate heat when they are used, they must also be connected to a cooling circuit. Each battery will need their own pump for the coolant to ensure that each battery pack ages evenly. This coolant will also help to maintain a suitable temperature by providing heat to the batteries in cold environments since they also are sensitive to lower temperatures. They also need to have a junction box that contains fuses and connectors. Each battery pack will have one high voltage cable with two connections going from the battery junction box to either the main junction box for the high voltage electric circuit or an intermediate junction box. Similarly, each battery pack will have one warm and one cold coolant line connected to it to ensure that the correct temperature is kept, since these batteries are relatively temperature sensitive. They also have one low voltage cable going to the battery junction box that helps run the electric components of the battery pack such as the coolant pump.

3.3.2.2.1. Chosen Battery Shapes

During the layout analysis many different batteries were used with different shapes. Some were already existing models at Scania and some designs were proposed in this master thesis. The ones which were used for the final versions of the layouts are presented below. On the outside of the battery packs the junction box can be seen which the electrical cables will be connected to. It is therefore necessary to ensure that the junction box can be reached by the user in each layout scenario since the user may need to access it in terms of maintenance purposes. The position of the junction box can be altered for each battery pack. The main difference between the battery packs is how the internal components have been stacked, which thereby affects the outer dimensions of the boxes. It is also assumed that the cooling connection will be smaller than this junction box and it is therefore not added to the battery models.

3.3.2.2.1.1. F-Batteries:

Conventional shapes under investigation at Scania.

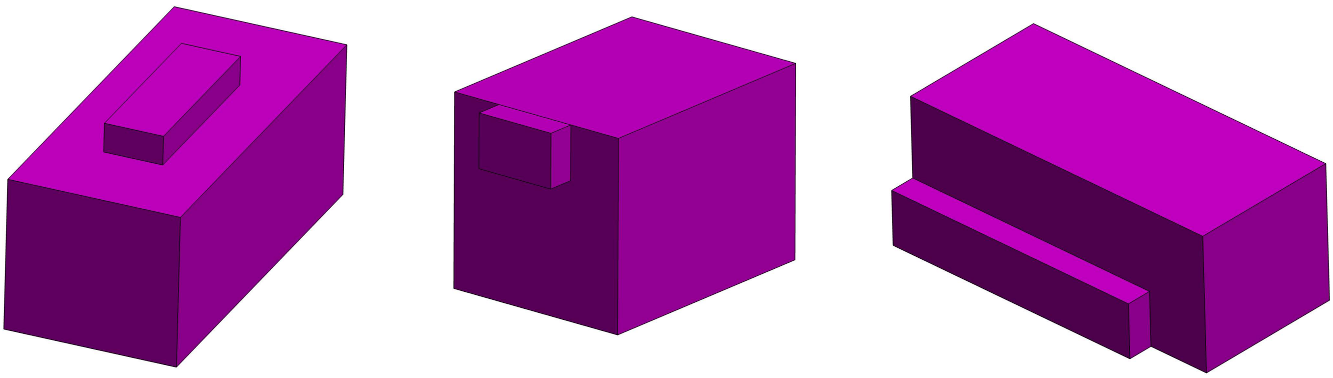


Figure 3.16 – F1 Battery Pack - F2 Battery Pack - F3 Battery Pack

3.3.2.2.1.2. C-Batteries:

C-batteries are complex shape batteries which can fit in non-rectangular areas due to their unique shape. C2 provides the unique advantage of containing the same amount of energy storage as two battery packs, but in one battery pack. This makes the battery pack offer more energy at the cost of increasing its size. However, since the battery pack dimension for housing and insolation can be shared it also means that the ratio of energy per volume increases.

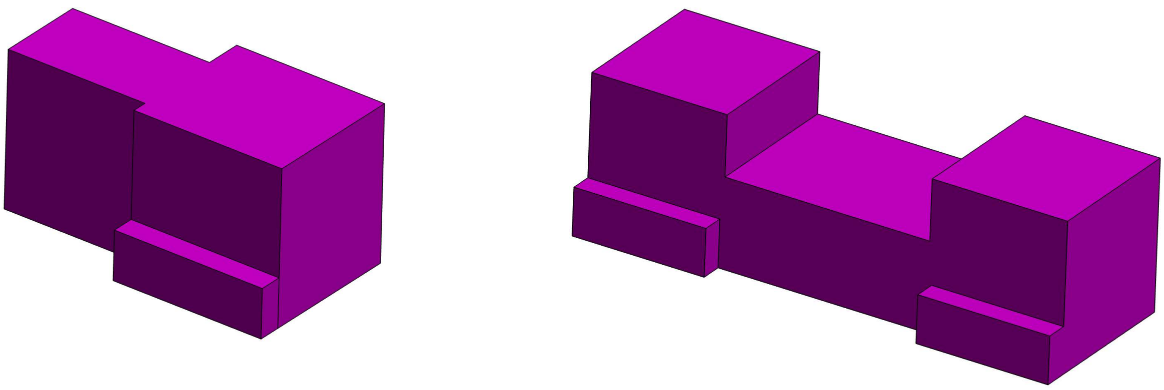


Figure 3.17 – C1 Battery Pack - C2 Battery Pack

3.3.2.2.1.3. S-Batteries

S-batteries are split into two separate boxes to utilize free space on the truck which is spread out in different compact areas. Two of these boxes are required to together form one functioning battery. Only using one of these boxes cannot function separately since it would deliver too low voltage to electrical circuit.

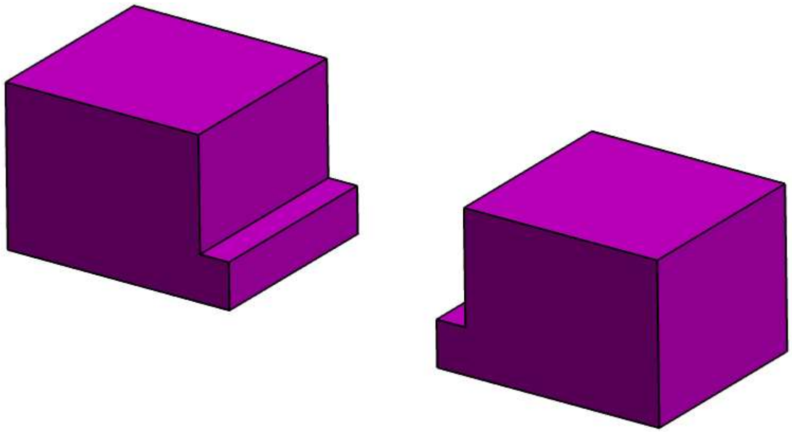


Figure 3.18 – S1 Battery Pack

3.3.2.2.2. Common Battery

When the engine is removed from underneath the cab then that area will always be empty. This makes this a suitable place to keep a battery for every scenario. Therefore, an F2 battery pack was placed there in the engine tunnel since it is suitable for all the performance steps of the cabs. The ground clearance interface, engine tunnel interface and cab suspension interface were followed when placing this battery there. The battery was also kept at a certain minimum distance for air flow away from the radiator fan to ensure that it did not negatively impact the performance of this component (Hall, 2019).

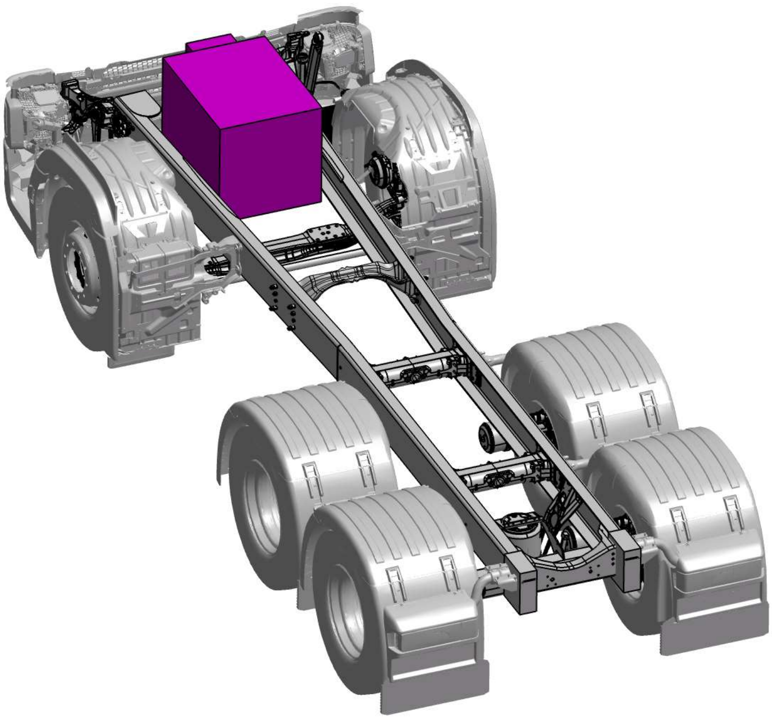


Figure 3.19 – Common Battery in Engine Tunnel

3.3.3. Power Electronics

The power electronics are components which support the high voltage electrical circuit and helps to ensure that it functions properly. Since there currently exist no performance series similar to this it has therefore been proposed to be added to the modular toolbox as seen in *Figure 3.20* below.

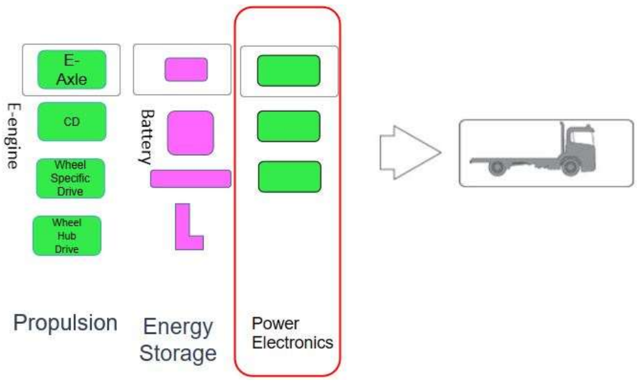


Figure 3.20 – Example of Power Electronics in the Modular Toolbox

One of the necessary power electronics is the inverter which helps to convert DC to AC. The reason for why it is necessary to supply the truck with AC is because the powertrain is assumed to operate at AC. Since AC is not possible to store in batteries it is therefore necessary to supply the truck with an inverter. This inverter must also be placed at a maximum of 2 meters away from the propulsion unit for it to function as intended. It is however assumed that the inverter will be integrated into the propulsion units in the future, which then eliminates the need of placing an inverter on the layout.

However, the inverter has been included in the scope of this master thesis to help show suitable positions for the inverter on the layout since it adds some restrictions which are essential to overcome when electrifying the trucks.

Many of the low voltage electrical components will be carried over from the existing modular toolbox to minimize the amount of development work for electric trucks. These low voltage electrical components include lighting, electrical components in the cab, etc. However, since the charging is only done to the high voltage propulsion batteries, and since the alternator has been removed, it therefore becomes necessary to supply the truck with a DCC (Direct Current Converter) which helps to maintain a suitable energy level in the low voltage batteries.

Additionally, it is necessary to supply the truck with junction boxes, also called Xboxes. The function of these is to interconnect the multiple battery electrical circuits together to the inverter for the propulsion unit. These junction boxes will come in numerous sizes, each offering different maximum amount of connections. It is ideal to place these between the frame along the axle distance to minimize the amount of cabling for the high voltage circuit. If the axle distance is increased and more batteries are used, then it is possible to increase the number of junction boxes to further minimize the amount of cabling and simplify the electrical circuit.

Fuse boxes are also added to the truck to minimize the risk of dangerous electrical accidents on the truck and to minimize the risk of damaging expensive electrical components. The fuses will break if there is an electrical fault and the surge of electrical current climbs too high, resulting in the electrical circuit breaking.

Finally, it will also be necessary to supply the truck with BMU (Battery Master Unit) and BSU (Battery slave Unit). The BSU is connected to each battery pack and helps to regulate the battery to ensure that it functions as it intended. The BMU is the main BSU which interconnects all the BSU together.

The relations of all the power electronics mentioned above can be seen in *Figure 3.21* below. Since the power electronic components are connected to each other it decided to place them in the same area of the truck to minimize the amount of cabling. It was also decided that it was best to keep these components in an area of the truck which is available for every layout since all trucks will need these power electronics. Therefore, it is strategical to have a standardized and reserved area for these components. The power electronics were placed on the battery pack in the engine tunnel since this space was always available and can be seen in Figure 22-23 below. This position also gives the user the ability to access the power electronics through tilting the cab. The only exception to this was the inverter which was placed directly on top of the CD and next to the E-Axle since it had to be a maximum of 2 meters away from the propulsion unit.

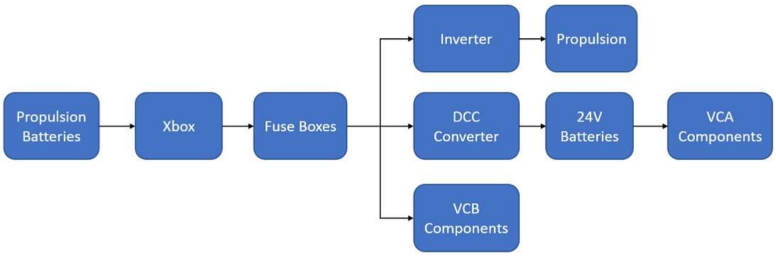


Figure 3.21 – Power Electronics Relations

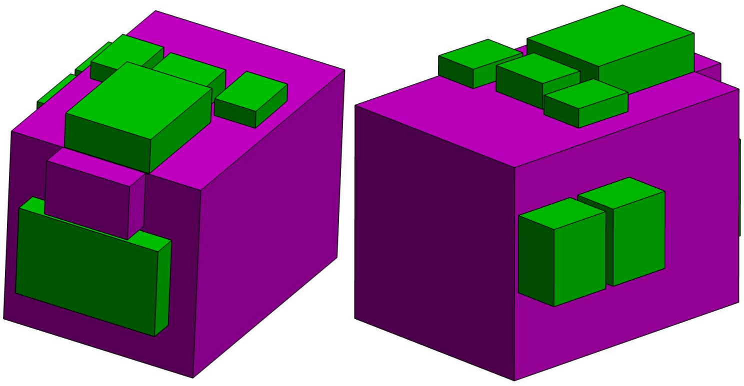


Figure 3.22 – Power Electronics on Battery Pack

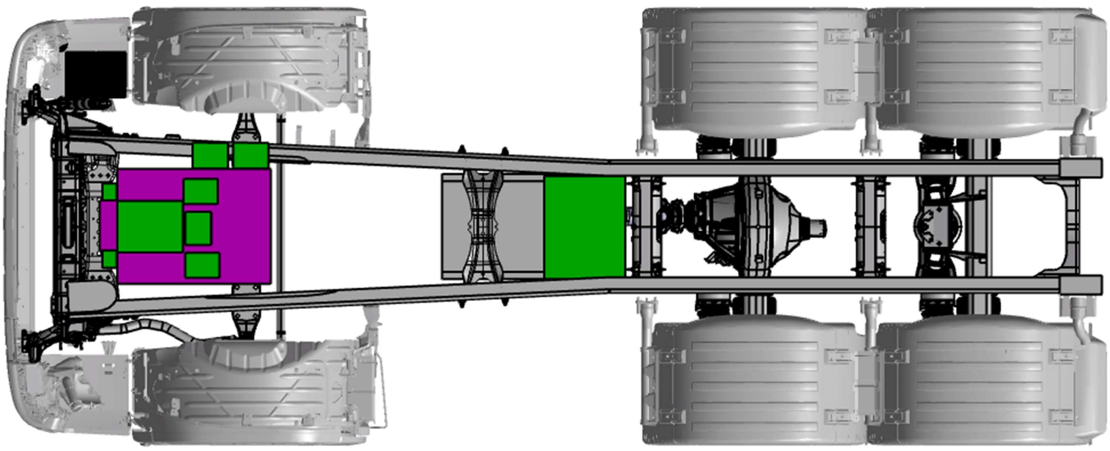


Figure 3.23 – Power Electronics

3.3.4. Charging System

The charging system consists of a charging interface which connects to the external energy source as well as a charging box which regulates the charging process. This helps to ensure that the batteries are correctly recharged with electrical energy. Since there currently exist no performance series similar to this it has therefore been proposed to be added to the modular toolbox as seen in *Figure 3.24* below.

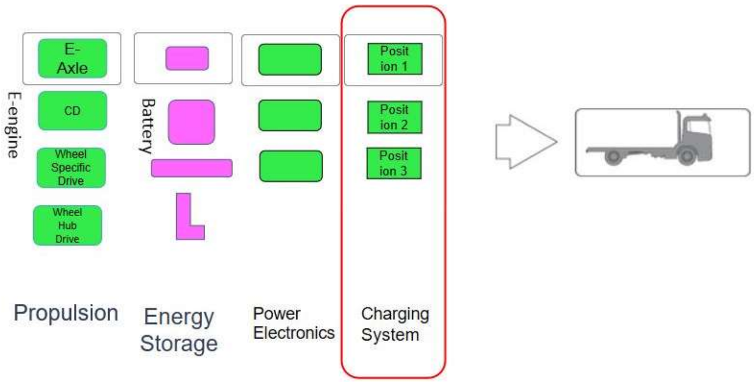


Figure 3.24 – Example of Charging System in the Modular Toolbox

Different users may have different needs in terms of where they wish to place the charging interface, since some may want to back up to a loading dock and charge it there and some may only want to have it on the side of front of the truck. Therefore, the possible charging interface positions can be offered through performance steps in terms of positions. During the analysis of possible charging positions, it was found that it is not beneficial to place it on the cab since the electrical cables are quite thick and therefore difficult to pull up to the cab. Additionally, these cables may wear down over time from the cab tilting due to their thickness. It was then found that one suitable position for the front of the truck was in front of the air inlet system since this area has been freed since an air inlet is no longer necessary. It is also a suitable height to offer an ergonomic user interface. Similarly, it was found that the mudguards were suitable to place the charging interface upon since they also were positioned at ergonomic heights and had much free space for the interface and cables. Since the mudguards are spread out over the truck it also opens many possible locations for the charging interface as can be seen in *Figure 3.25* below. It can be seen in *Figure 3.26* that when the interfaces are placed, they need to take other layout interfaces, such as the trailer interface, into consideration to ensure that they do not clash.

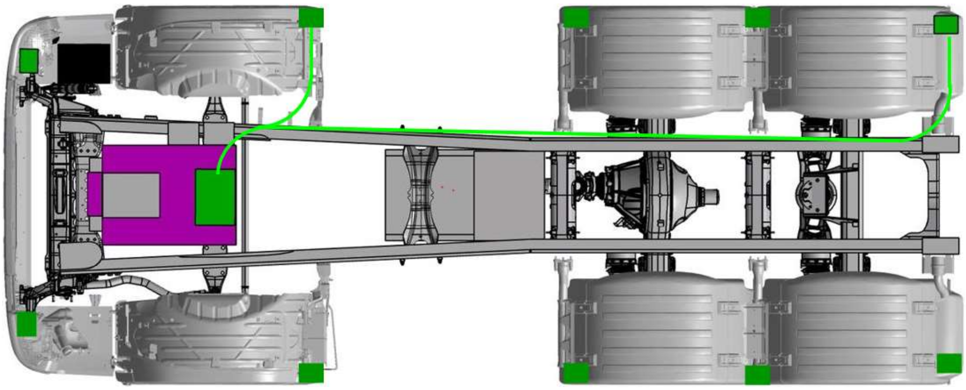


Figure 3.25 – Charging Components Positions

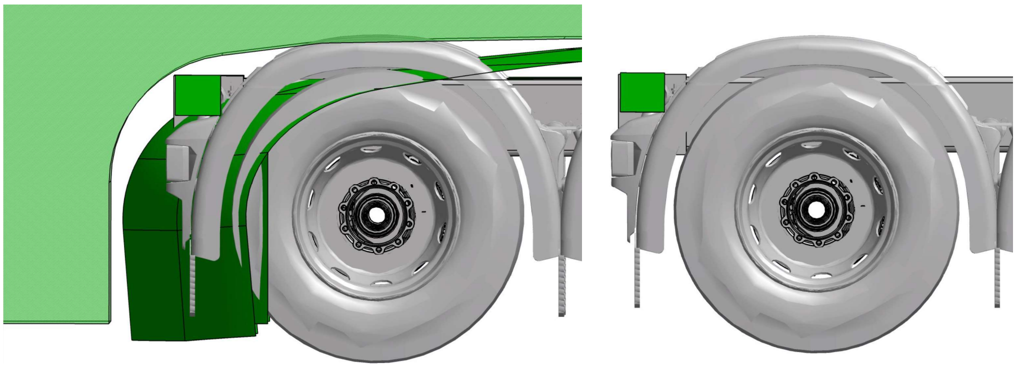


Figure 3.26 – Rear Charging Interface Space Restriction

It should be noted that in the future, instead of storing large amounts of electrical energy on the truck, it may instead be possible to store smaller amounts of electricity and continuously charge the truck while it is traveling on certain roads. This would then mean that the truck would only need to store enough energy to travel from this continuous charging to the designated destination. One of these concepts is called E-Highway where electricity is constantly available at the road. It can then be transferred to the trucks through pantographs that work very similarly to trains and trams, as can be seen in *Figures 3.27* and *3.28* below. The pantographs will rise when entering the E-Highway and decline when leaving the highway. However, since this would greatly impact the amount of energy storage needed on the truck, and since it is still not known if this concept will be realized with a full infrastructure in the future, it is therefore not further analyzed in this thesis.

Figure 3.27 – Pantograph Charger (Scania CV AB, 2018)

Figure 3.28 – Pantograph Charger (Scania CV AB, 2019)

3.3.5. Temperature Control System

The cooling system will also be affected by the electrification of the trucks. Since the electrified powertrain is more energy efficient compared to the ICE it also means that less heat will be generated. However, since the electrical components are more temperature sensitive it will limit the appropriate temperature range that these components can operate within. Due to this, the name of the cooling system is changed to Temperature Control System (TCS) since the temperature of the batteries and the cab will be regulated by both adding and removing heat. At the same time, it also becomes more difficult to exchange heat with the environment since the rate that heat can be exchanged with the surrounding air is affected by the difference in temperature, which is now lower (Hall, 2019). This puts a higher demand on the cooling system since it now will become even more important to develop a highly effective cooling system for electrified trucks to ensure that all electrical components can function correctly during their intended life span. An example of how the TCS performance series may look in the modular toolbox can be seen in *Figure 3.29* below.

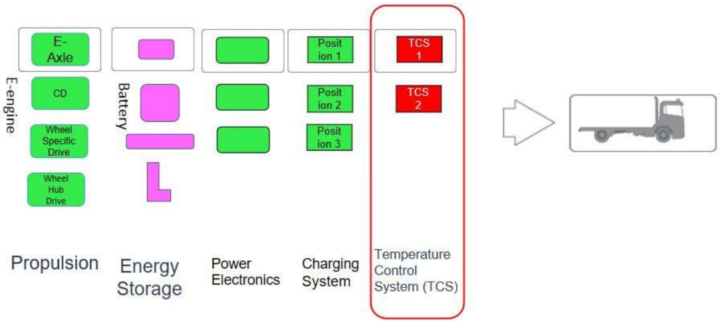


Figure 3.29 – Example of TCS in the Modular Toolbox

It is preferred to use typical coolant mixtures instead of oil in the cooling circuits since it is more difficult to move oil due to the increased pressure drops and increased energy consumption from operating the cooling system (Hall, 2019). Additionally, the installation of oil coolant components is significantly more expensive which might increase production costs. However, it should be kept in mind that the pressure drops and difficulty to pump around the oil is mostly over longer distances, such as along the length of the truck. Should the oil only travel shorter distances then it can be argued to use it if it presents significant benefits. In the short term it may be necessary to use propulsion components which use oil cooling due to the limited range of possible solutions. But in the long term it is nonetheless beneficial to strive towards removing it if possible.

It has been decided to keep all radiators in the front of the truck to utilize the ram air to improve the performance of the radiators. The radiators should also be placed in order of colder to warmer where the warmest radiator is closest to the radiator fan. The reason for this is that this placement will help to ensure that the effectiveness of the system is as high as possible since the warm radiators will not limit the performance of the colder radiators as much (Hall, 2019). It was also decided that the distance between the rearmost radiator and the radiator fan should always have the same standardized distance. The reason for this is that it will help to minimize costs since the molding tool which is used to create the fan cover is expensive (Hall, 2019). It thus becomes unnecessary to have different dimensions in this region since it does not create any benefit. Since each radiator will require some means of mounting them to the truck, it is also proposed to design a common holder for all the radiators to minimize complexity in production and to follow the modular method of reducing the number of unique parts. However, this must be further investigated.

Since there no longer is an ICE it also means that it will become necessary to find an alternative source of power for the radiator fan. There currently exist some electrically powered radiator fans in the market which can work without using an ICE. However, due to limited development in this area these fans are smaller since a larger electrically powered fan would require a much stronger electrical motor with more torque. Due to this, Scania's current solutions use two smaller electrically powered radiator fans. To compensate for the smaller size of the fans these must then operate at a higher rpm to deliver the same flow of air as a bigger fan. The result of this is an increase in noise level from these fans (Hall, 2019). However, from interviews it has been discussed and assumed that a stronger motor alternative will be developed in the future which will then make it possible to only use one electrically powered fan. This is a more attractive alternative since this would decrease the noise level from the truck. It is therefore recommended to in the long term strive for a one electric radiator fan solution. An example of a radiator fan with a single electric motor can be seen below. A certain small gap should be kept between the radiators and the radiator fan and another gap between radiator fan and the components behind it. The later gap is also dependent of whether the component behind it is placed centrally behind it or slightly to the side.

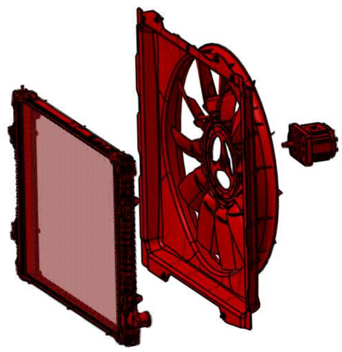


Figure 3.30 – Radiator and Radiator Fan

All the battery packs will need cooling since they generate heat when they are used. They should all also have the same cooling performance to ensure that they all have the same life span. Temperatures outside of the intended temperature span will in the long term negatively affect the battery packs and will thereby decrease their life span. Therefore, each battery pack should be equipped with a coolant pump to regulate the individual coolant flows to ensure that all the battery packs age evenly (Hall, 2019). Due to the previously mentioned difficulty of exchanging heat for electric trucks, the cooling circuit for the battery packs will need to have cooling from an AC system to achieve the desired cooling effect. This AC can be shared with the cab to minimize complexity as well as production cost (Hall, 2019). The added power electronics and powertrain will also need cooling since these components generate heat when they are used.

The AC system will function as a heat pump which means that it can generate both heat and cold for the TCS. Similarly, small amounts of electricity can be deliberately be sent at low efficiency into the power electronics components to generate some heat that can be used to heat the cab (Hall, 2019). Similarly, the heat by-product from the batteries can also be utilized to heat the cab. The AC compressor will need an alternative source of power since it can no longer be directly connected to an ICE engine. The cab can also be equipped with an auxiliary heater to energy efficiently provide heat to the cab when the user wishes to sleep inside the cab (Hall, 2019). Also, instead of separately heating and cooling different systems it is possible to exchange heat between them to maximize energy efficiency. However, these connections might become complex and it must be carefully controlled so that heat from one system does not damage another since different components may operate within different temperature spans.

Below in *Figure 3.31* the functional relations between the cooling system and related components are visualized. It can here be seen that the cooling package, which consists of radiators and the radiator fan, supplies cold coolant to the batteries, power electronics and powertrain as mentioned above. However, since the batteries are more temperature sensitive than the other components, they will require additional temperature control. As mentioned above, the AC system can provide both heat and cold and is therefore connected to both the batteries and the cab climate to keep both within the desired temperature span. Similarly, the auxiliary heater is connected to both the batteries and the cab climate to energy efficiently provide heat to these systems when it is necessary. To further keep the system as energy efficient as possible the cab climate is connected to the warm coolant circuit to utilize the heat to the highest level as mentioned above.

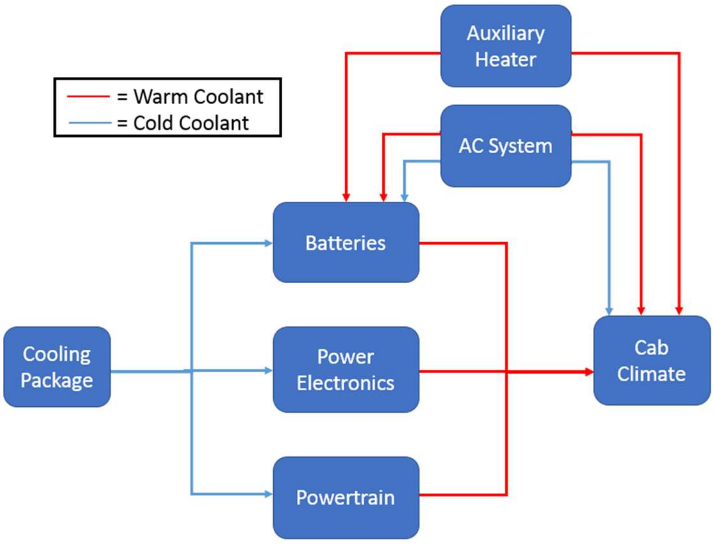


Figure 3.31 – Functional Relations Components Cooling System

All the auxiliary components needed for the temperature control system such as pumps, heat exchangers and AC system are all kept within in a box that is placed under the battery in the engine tunnel. The reason for this is that all trucks will need to have all the TCS components to function properly. Therefore, it is strategical to find a location which can be reserved and standardized for these components. This also helps to minimize the amount of piping since the travel distance is shorter. The placement of this box can be seen below in *Figure 3.32* and *3.33*.

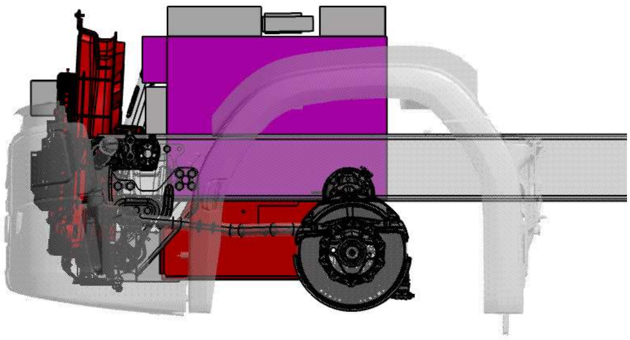


Figure 3.32 – TCS Placement

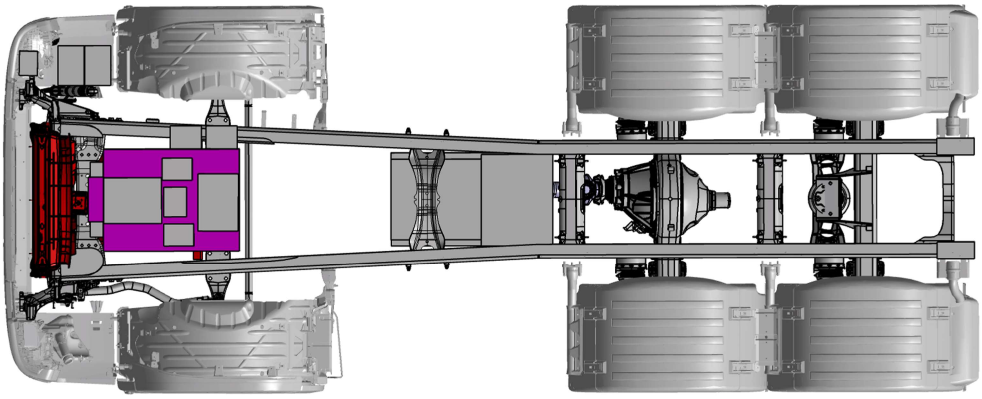


Figure 3.33 – TCS Placement

3.3.6. Compressed Air

The compressed air is used as a control media for numerous systems in conventional ICE trucks. The air is compressed by a compressor which is powered by the engine, processed in an Air Processing System (APS) to remove humidity and is then finally stored in multiple air tanks spread out on the vehicle. When necessary, components in need of compressed air then utilizes this stored compressed air. The systems which use compressed air includes primary brakes and retarders, cab and chassis suspension, chair movement in the cab, trailer control, etc. However, since this master thesis is not analyzing the cab or the trailer those components are therefore not included in this analysis.

When the engine is removed then the source of power for the air compressor is also removed, meaning that a new means of compressing the air is necessary. An alternative solution was found in Scania which is an electrically powered external air compressor which can be mounted to the side of the truck. This solution gives the opportunity to re-use all the other compressed air components from the ICE trucks. It should be noted that this component will require cooling from the cooling circuit as well as high voltage energy supply.

However, the components of the compressed air system occupy a lot of volume on the trucks, especially the electrified air compressor. Additionally, the compressed air system has a relatively low energy efficiency which is something that is beneficial to remove form electrified trucks since energy efficiency becomes something very important to strive towards with electrified trucks. Therefore, it is beneficial to investigate more energy efficient alternative means of controlling these systems.

However, since Scania builds their trucks with a modular approach it should still be possible to offer trucks with compressed air components if it is desired by the customer. Therefore, an analysis was done to see how brakes and suspension with and without compressed air could be mixed. This can be seen in *Figure 3.34* below and it should be noted that components of insignificant size are not included in this Figure.

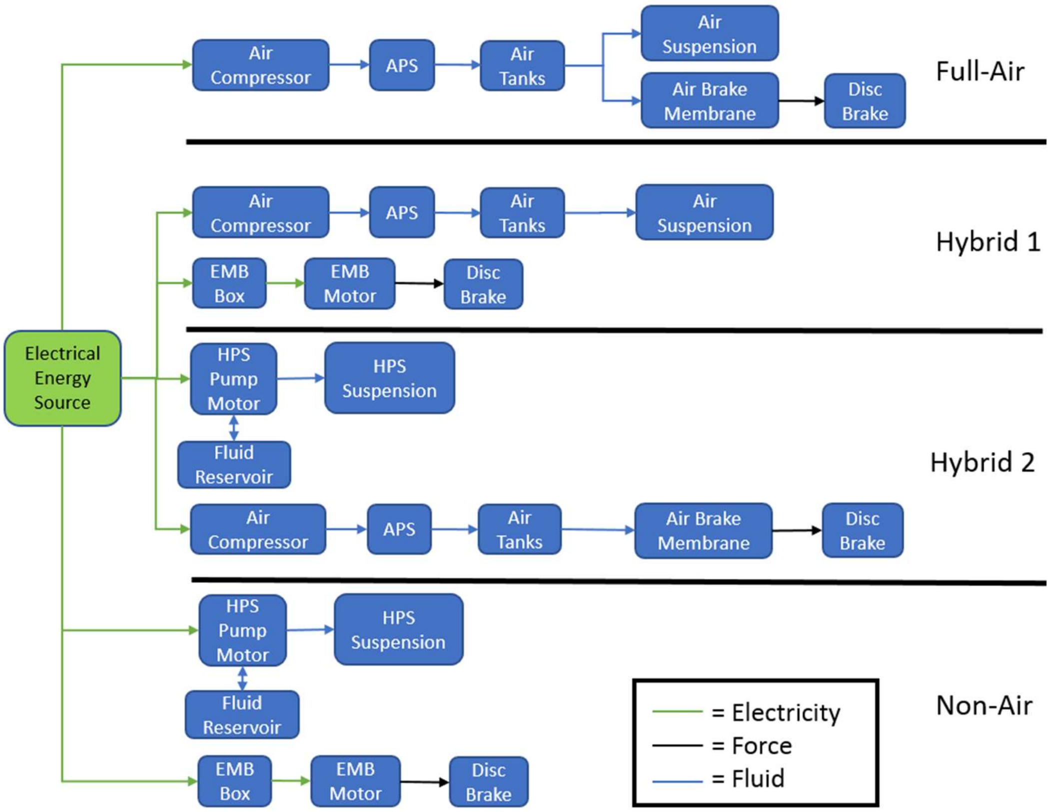


Figure 3.34 – Compressed Air Analysis for Brakes and Suspension

After analyzing the different combinations is was realized that if compressed air was used on a truck, then it might as well be used for all components. The reason for this is because one of the biggest drawbacks with the compressed air system is that it requires an air compressor and an APS which occupies much volume on the truck and contributes much to the low energy efficiency of the system. However, the occupied volume of these components is the same regardless of how many components they are used for, meaning that one compressor and APS is always used, but the number of compressed air tanks and powered components may vary depending on the layout. Therefore, it is strategical to not mix the usage of compressed air and non-air components on the truck since it will limit the benefits of using the non-compressed air components on the truck. Therefore, when analyzing the layouts later in this report comparisons will be done for compressed air vs non-air but not for a mixture between the two.

3.3.7. Steering

3.3.7.1. How Steering Currently Works at Scania

The steering system is what allows the user to control the traveling direction of the truck by altering the angle of the wheels on the steered axles. The user turns the steering wheel until the desired turning radius is achieved on the truck. As the user turns the steering wheel this rotation is transferred mechanically to a power steering unit where the torque output to the wheels is amplified. The reason for using a power steering unit is that it is exhausting and unergonomic for the user to manually apply enough torque to the steered wheel to acquire the desired steering performance. Typically, not using any power steering will also require a larger steering wheel to increase the input torque from the user. This will result in bad ergonomics and will be much more exhausting for the user.

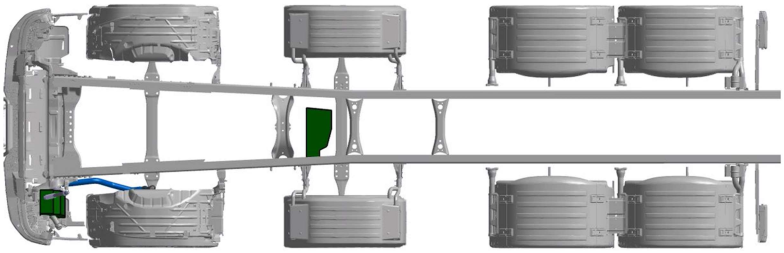


Figure 3.35 – Double Steered Front Axles

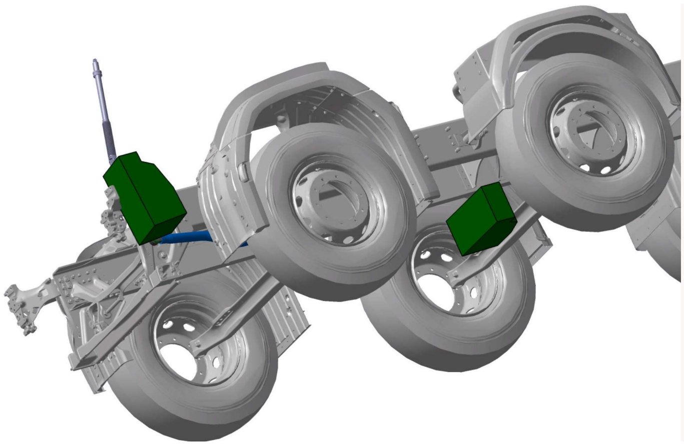


Figure 3.36 – Double Steered Front Axles

If there is an additional steered front axle, then this is today mechanically connected to the first steered axle so that they always have the same steering angle to ensure that the same turning radius is achieved for both steered axles. If the truck is equipped with an additional steered axle in the rear, then this is currently solved by Scania by using an electro-hydraulic Tag axle Steering (EST) on this axle. The EST works by mounting a hydraulic press on the steered axle which is powered by an electric pump to alter the angle of the wheels. This solution receives a signal which specifies the desired turning radius from the user input on the steering wheel. The EST simply turns one of the wheels, and since both wheels on the same axle are connected by a track rod they will then turn at the same time. An example of an EST similar solution by Bosch can be seen in *Figure 3.37* below.

Figure 3.37– Bosch Rear Steering (Bosch, 2018)

3.3.7.2. How it is Affected by the Electrification

The steering will be affected by the electrification since the power steering is currently powered by an auxiliary pump located on the engine. If the engine is removed, then an alternative source of power becomes necessary for the power steering to function properly. Some alternative power steering solutions were therefore analyzed and are described below.

3.3.7.3. Alternative Solutions

Electro-Hydraulic Steering (EHS) is a hydraulic power steering which is powered by a separate electric pump instead of using an auxiliary pump on the engine. This works similarly to the EST described above with the exception that the pump must constantly be running.

Figure 3.38 – EHS (Bosch, 2018)

Electrically Assisted Steering (EAS), also known as Servotwin, is basically an EHS with an additional electric motor mounted on the input shaft which helps to better control the power steering (Bosch, 2018). This concept is basically a smarter EHS solution since the various parameters on the truck together with angle and torque sensor connected to the steering wheel help to calculate how the wheels should turn. The additional electric motor on the input shaft then applies the additional necessary torque or rotation to the power steering to achieve this. This functionality helps to improve comfort, lane keeping, side wind compensation, etc.

Figure 3.39 – Bosch EAS (Bosch, 2018)

Electro-Powered Steering (EPS) is a fully electric power steering which can offer power on demand. This will in turn help to minimize energy consumption which can both minimize operation costs and increase range to a small degree. The driver will also be able to steer the truck with varying gear ratio which could be useful in situations such as parking and roundabouts where truck driver may need to greatly change the turning radius often. Compared to the other power steering solutions the EPS is the most integrated solution since all its necessary components are built into one body. This means that the EPS is less spread out on the truck and has less relations to other components. However, from initial designs this integrated solution will be slightly larger in size in comparison to the alternatives.

Figure 3.40 – Bosch EPS (Blakemore, 2018)

In addition to changing the power steering unit the entire steering system can be redesigned for future trucks. One interesting concept is steer by wire which essentially is a steering system which has no mechanical linkage between the driver and the wheels. This means that the steering system is completely controlled by signals. According to Davies (2014) this concept will bring forth numerous advantages such as faster steering response, improvement of the active lane control system, reduced weight and reduced maintenance. From interviewing Peter Karlsson (2019) it was also mentioned that this concept might make it possible to increase the maximum steering angle which can in turn improve handling in space limited environments. It was also mentioned that the removal of the mechanical connection will make it easier to produce left and right hand vehicles since they can share the same layout of the steering system, except for inside the cab. This solution would also free up some space around the conventional power steering position since the power steering component can instead be placed more freely. An illustration of steer by wire can be seen in *Figure 3.41* below. It is there seen that turning the steering wheel will send signals to the steered axles to make it turn, and artificial torque will be sent back to a motor connected to the steering wheel to give the driver a better perception of how the wheels are turning as well as feedback from the road terrain.

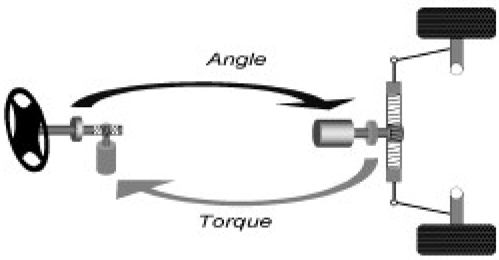


Figure 3.41 – Steer By Wire Concept (Mallikarjuna, 2017)

However, since there currently exists no design of a steer by wire concept at Scania it must be further investigated. Other fields which uses steer by wire can be analyzed to get a better understanding of how the technology can be designed and used. Some examples of fields which uses steer by wire includes steering in airplanes, brake and throttle control in cars, etc. As of now it is known that it will be necessary to add a steering wheel actuator in the cab to receive the steering input and transform it into signals (Karlsson, 2019). Additionally, it will be necessary to have a motor mechanically connected to the steering wheel so that the steering returns to its origin when untouched. This motor could also be used to supply force feedback to the driver to increase the perception of the road condition. As mentioned before, the removal of mechanical connections will allow the steer by wire to be designed in a way which will increase the turning radius of the truck. However, it will then be necessary to use a suitable power steering solution which will support this. Using a design similar to EST is undesired since the solution will not be able to turn the wheels to such extended degrees. Instead, it is better to design the power steering with a rotating output shaft and somehow connect this to both wheels. Additionally, should an EPS solution be used then the size of this solution can be significantly reduced since many of the internal components are no longer necessary when the mechanical connection is removed from the steering system.

During development of the steer by wire concept it is also important to regard other factors, such as how the interior of the cab is affected. It needs to be analyzed if the new components will increase the noise level in the cab, such as from the added force feedback motors, and how to install these components in the cab. Additionally, since there currently exists many assumptions regarding high levels of autonomous vehicles in the future it needs to be ensured that the steered by wire is designed to fit these trucks as well to ensure that the modular toolbox is utilized to the maximum extent.

3.3.7.4. Proposed Solution

The proposed alternative solutions above all have their own advantages and disadvantages. From a time perspective they may also have different time to market periods due to the status of the development. Therefore, it may be beneficial of Scania to provide all of these in the future in terms of possible performance steps. However, if these alternatives are compared to see which is superior then it was found that systems that were not power on demand were less attractive since they resulted in increased energy consumption. If those alternatives were removed, then the remaining alternative is the EPS which could offer power on demand. It is therefore proposed to strive development towards EPS since it would in the long term be the most beneficial to the customers and users. However, the integrated design of the EPS resulted in a larger body which made it more difficult to place on the truck. When the EPS was placed in the position of the existing steering gear, which is the front left corner of the truck, it was seen that it clashes into the washer system, lighting and APS. As mentioned, this design of the solution is preliminary and thus one or many of the affected components in that area need to be adapted to fit with the EPS. The placement of the EPS can be seen in *Figures 3.42* and *3.43* below where the green box is the EPS.

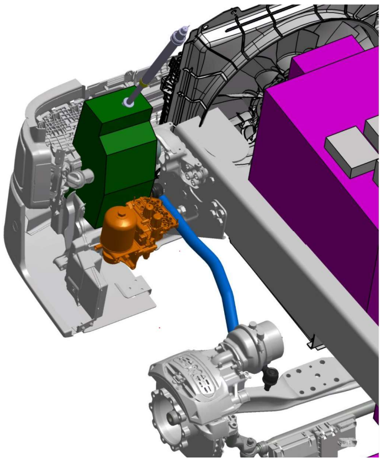


Figure 3.42 – EPS Placement

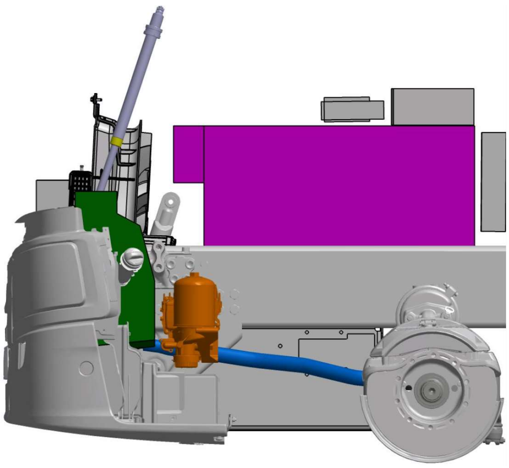


Figure 3.43 – EPS Placement

Since the Steer by wire is still conceptual with no existing designs as well as low impact on the layout it has been decided to continue with the conventional mechanical steering since it can result in increased insights with regard to how to implement the EPS in the space limited front area of the truck since the EPS must use the existing positions. For rear steered axles EST will still be used at the same position due to its compact design and independent functionality. An example of how the steering performance series may look in the modular toolbox can be seen in *Figure 3.44* below.

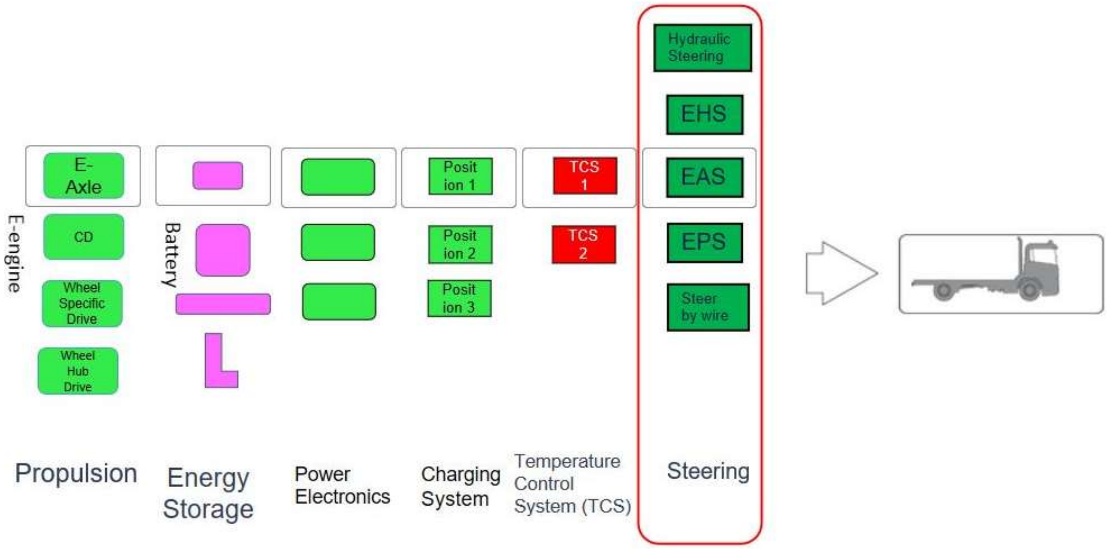


Figure 3.44 – Example of Steering in the Modular Toolbox

3.3.8. Suspension

3.3.8.1. How it Currently Works at Scania

Suspension is used to improve the ride quality by minimizing the impact of shock forces caused by differences in the driving terrain and keeping the truck balanced on the road. It thereby helps to maintain vehicle stability, minimize wear on components and increases the driver's comfort. Suspension is comprised of springs, shock absorbers and mechanical linkages that connects the vehicle to the wheel axles. Scania offers different performance steps on suspension, ranging from mechanical suspension, air suspension or a combination of both.

The mechanical suspension is also referred to as leaf spring suspension and can be either multi-leaf or parabolic suspension, out of which multi-leaf is robust and is used for larger loads such as the ones in construction and mining application whereas parabolic is simple and light weight which allows for better comfort and increased payload for customers (Scania, 2019). Air suspension is low weight and is supported by compressed air bellows and shock absorbers to provide comfort and good driving performance. Air suspension occupies more space and is more expensive whereas leaf spring is heavier and cheaper.

3.3.8.2. How it is Affected by the Electrification

For electric trucks leaf spring suspension will not be affected by the electrification since it is purely mechanical. whereas air suspension provides an opportunity to reduce space on the vehicle thus allowing more space for batteries. The air suspension can also be used for electric trucks if an external electric air compressor is mounted to the truck. However, due to the previously mentioned drawbacks of this system it is beneficial to investigate other alternatives. Additionally, since different customers have different needs it is also beneficial to offer alternatives with different properties. It should also be noted that the cab currently uses compressed air for its suspension. An alternative solution must therefore be provided for the cab if the compressed air system is no longer used on the trucks. However, since this master thesis is not analyzing the cab, an alternative solution has therefore not been analyzed.

One attractive alternative which was found was Hydro Pneumatic Suspension (HPS) which is a refined version of hydrolastic suspension which has been in use since the 1950s. HPS replaces air with hydraulics as the suspension medium which requires a hydraulic cylinder, oil reservoir and a pump to function. HPS also uses a compressed gas accumulator with nitrogen as a shock absorber. These components are significantly smaller than the components that were used for air suspension which makes HPS compact solution that provides weight reduction close to 50 kg per axle while also improving the handling capabilities. Furthermore, it provides better energy efficiency compared to the air suspension which makes it an even more attractive alternative. This solution however comes at the cost of reduction in ride comfort due to the piston seal friction in the system which is why it has been limited to heavy vehicles until now. However, since space and weight reduction and energy efficiency are significant factors when it comes to electric vehicles it is still a viable solution.

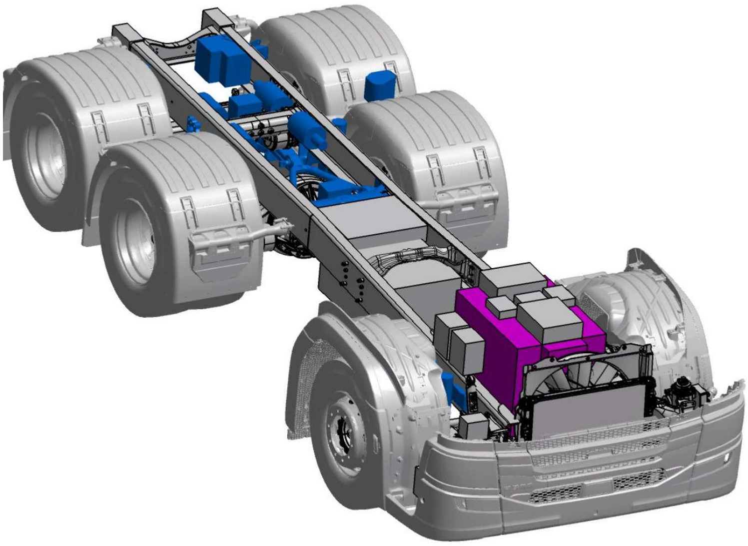


Figure 3.45 – HPS Placement ISO View

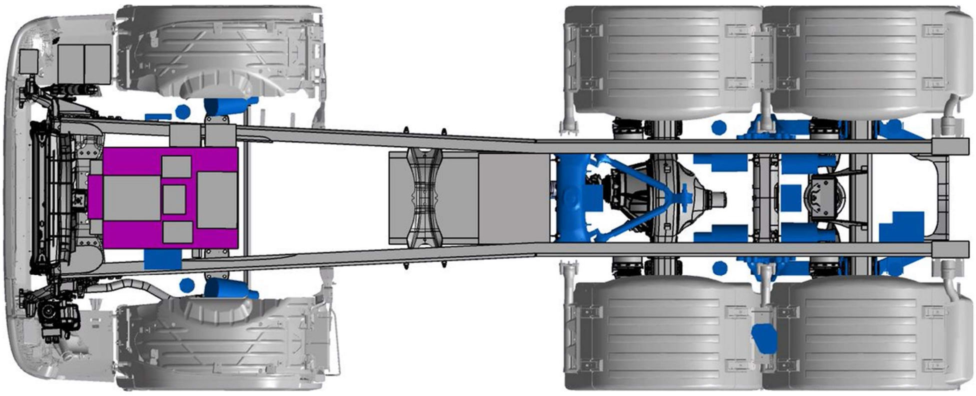


Figure 3.46 – HPS Placement Top View

There also exists solutions on the market that do not rely on pneumatic or hydraulics. Instead these use a form of mechanical suspension which is controlled by electric circuits. One such solution is the active suspension used by Audi in its new Audi A8 model car which can be seen in Figure 3.47 below. Audi uses a 48 V electro mechanical suspension. Each wheel is equipped with an electric motor that exerts the needed force on the suspension through a coupling rod. This helps in adjusting the suspension of each wheel individually based on the road conditions thus providing utmost comfort and dynamism to the customers. This solution looks promising but has limitations when it comes to the suspension force that it can exert which proves critical for its use in heavy vehicles such as trucks. Therefore, it will no be used in the coming layout analysis. An example of how the suspension performance series may look in the modular toolbox can be seen in *Figure 3.48* below.

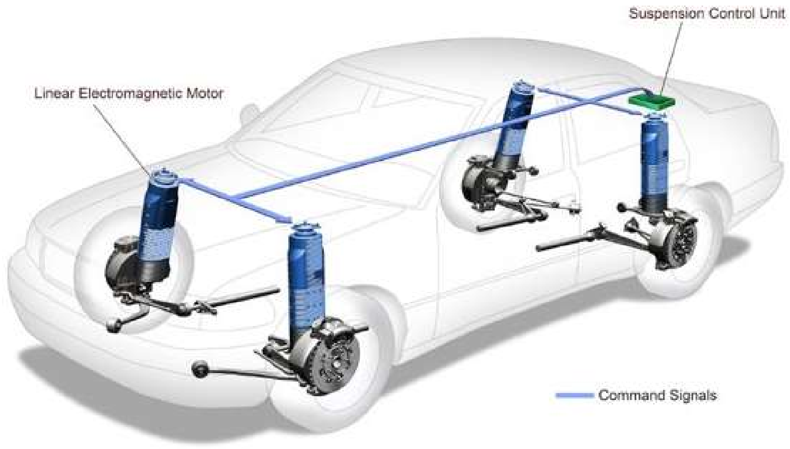


Figure 3.47 – Audi Electro Mechanical Suspension (Teslarati, 2019)

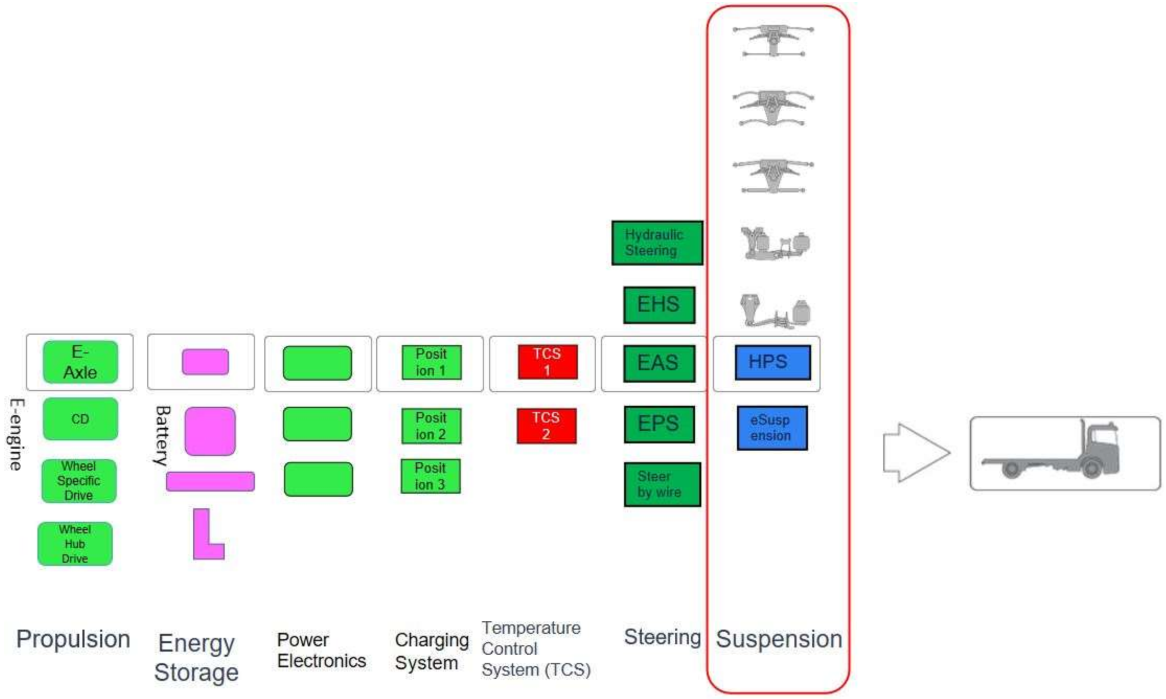


Figure 3.48 – Example of Suspension in the Modular Toolbox

3.3.9. Brakes

3.3.9.1. How it Currently Works at Scania

The brake system is what allows the driver to deaccelerate the truck when it is desired. Due to legal reasons Scania equips their trucks with multiple brake systems such as service brakes, emergency brakes and auxiliary brakes. The service brakes are the primary brake system which can be easily controlled by the driver. Scania typically uses disc brakes as their service brakes on their trucks but also offers drum brakes to their off-road market segment. All of Scania's brakes uses compressed air as the control media since compressed air is readily available on the truck. Additionally, the truck is equipped with emergency brakes also known as secondary brakes and parking brakes which can be used to ensure that the truck does not move when it is parked. It can also be used to deaccelerate the truck in case the primary brake system is not working. The legal requirement for the emergency brake states that if the primary brake fails, secondary brake should be able to provide the required braking performance by any available means (Lundgren, 2019). Therefore, the emergency brake used today is integrated into the service brake to minimize occupied space on the truck and can be manually engaged by the driver.

Finally, from a legal perspective the truck must also be able to offer braking performance over a longer period when traveling downhill. This will require converting a lot of kinetic energy into heat and it is usually solved by Scania thorough equipping the trucks with an auxiliary brake which could be either a retarder or exhaust brake (Scania, 2019). A retarder is connected to the transmission and converts mechanical energy into heat and then transports away this heat using a cooling circuit and a radiator. Since the retarder converts the energy by accelerating fluids it results in low wear on components which makes it a suitable low maintenance brake system. Similarly, the trucks can be equipped with an exhaust brake which also helps to deaccelerate the truck. The exhaust brake closes the path to the exhaust system which builds up pressure in the cylinders and thereby slows down the engine when fuel is not injected. This can be used to deaccelerate the vehicle and can also be used to supplement other braking systems when both systems are engaged at the same time.

3.3.9.2. How it is Affected by the Electrification

The current brakes at Scania are all controlled by compressed air. As mentioned earlier, removing compressed air from the truck may present some advantages which thereby lifts the need to investigate alternative brakes which works independently of compressed air. An analysis was thus performed regarding various brake technologies on the market to see what type of brakes exists and which of these are most beneficial to implement on an electrified truck.

Some alternative solutions were found which used alternative medias to control the brakes. These include oil, compressed air and electricity. However, since electricity is already available on electric trucks and the necessary components needed to have compressed air or oil to control the brakes requires additional space, it is then more strategical to use electricity as the control media since it will result in a much more compact solution. This is highly desirable from a layout perspective.

During the analysis of using electricity as a control media for brakes it was found that Scania is proposing to develop Electro Mechanical Brakes (EMB). This solution has the potential to be compact on the layout since it does not require any compressed air or similar medias to function properly. From interviewing Lundgren (2019) it was also evident that it will consume less energy which can help to increase the range of the vehicles and minimize operating costs. Unfortunately, since there is currently no regulation in the EU market regarding EMB it is not possible to implement yet. However, due to the long-term scope of this project, and Lundgren's assumption regarding roughly five to ten years until EMB becoming implementable, it will still be regarded as an attractive brake solution to use in future electrified trucks.

The EMB uses motors to press the brake pads against the friction surface to generate the decelerative forces. The EMB can function as both service and emergency brakes since when the truck is parked then the motors will simply remain in a pressing position. The size of the brakes for EMB will be roughly the same size as the currently existing corresponding components used with compressed air. For this EMB system to function properly and safely it will require one control unit and one battery pack per axel which together will roughly require 15 liters of free space, as can be seen in *Figure 3.49* below. The reason why the EMB requires a control unit and a battery pack on every axel is to ensure that the system is fail safe by providing individual braking performance even if one of the control units or battery packs of an axle malfunctions. By equipping each axel with a battery pack of its own for the brakes it will also ensure that braking performance is available even if the rest of the electrical circuits on the truck malfunctions, making the brake system fail safe. Since the electrical circuit for EMB will assumedly operate at 48 V and 2 kW peak power the cables will thus be relatively small and not require much space.

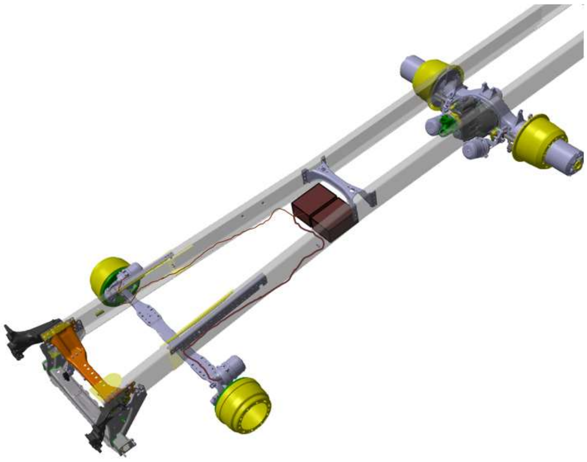


Figure 3.49 – Electro Mechanical Brakes Concept

Conventionally Scania has also equipped their trucks with auxiliary brakes. However, one of the big advantages of using an electrified powertrain is that the propulsion motor can perform regenerative braking which decelerates the vehicle and charges the batteries at the same time. This type of braking is optimal since it converts and stores the excess energy instead of converting the kinetic energy into heat and wasting it by heating the surrounding air. However, this regenerative braking will only work when the batteries are not fully charged. If the batteries are fully charged, then it no longer becomes possible to perform regenerative braking since it will damage the batteries by overcharging. However, for this scenario to occur it requires the truck to be fully charged while going downhill which is an unlikely scenario involving a charging station to be placed on the top of a long hill. However, due to legal reasons the electric trucks today must be fully charged while doing brake testing while going downhill. Due to this, electric trucks today need to be equipped with a retarder or similar solution.

However, since many of the concepts for the electric powertrains have limited free space surrounding them there is a risk that a retarder will not fit in that area. Due to this, it is also beneficial to investigate alternative solutions which can be placed freely. After studying alternative solutions, it was found that Mercedes-Benz Trucks has a brake resistor that converts generated electricity from regenerative braking into heat (Hammerschmidt, 2016). The advantage with this solution is that it can be placed anywhere on the layout of the truck since it does not have to be mechanically connected to the transmission. This solution could also be altered to utilize the generated heat by sending it to the cooling system to heat the cab. Similarly, the heat pump in the AC system could be used instead of a brake resistor to take away the excess electricity. However according to Ola Hall (2019) the power generated from regenerative braking while going downhill is too high to be sent to the existing cooling system since it would heat the system too much. It would then be necessary to equip the cooling system with an additional circuit. Due to this, these concepts are no longer used in the analysis.

However, according to Lundgren (2019) the regulation regarding the requirement of fully charged batteries during brake testing while going downhill will most likely change in the future. Therefore, it might not be necessary to equip the truck with a retarder or brake resistor in the long term since the regenerative braking will most likely always be enough and can be supported by the primary brakes when necessary. Since Lundgren stated that he strongly believes this regulation will change in roughly five years it is therefore proposed to not include a retarder or brake resistor in the layout analysis of this master thesis. With that knowledge an example of brakes in the modular toolbox can be seen in *Figure 3.50* below. It should be noted that regenerative braking generates power in the range of 130-200 kW based on the truck load. Therefore, it requires larger batteries on board to store energy of this magnitude. For an electric truck with less amount of energy storage, such as an E-Highway truck, it might still require a retarder or a brake resistor as an auxiliary brake since the batteries won't be able to handle the regenerative braking. For an E-Highway truck this will occur when the truck is going down on a hill with no electric lines.

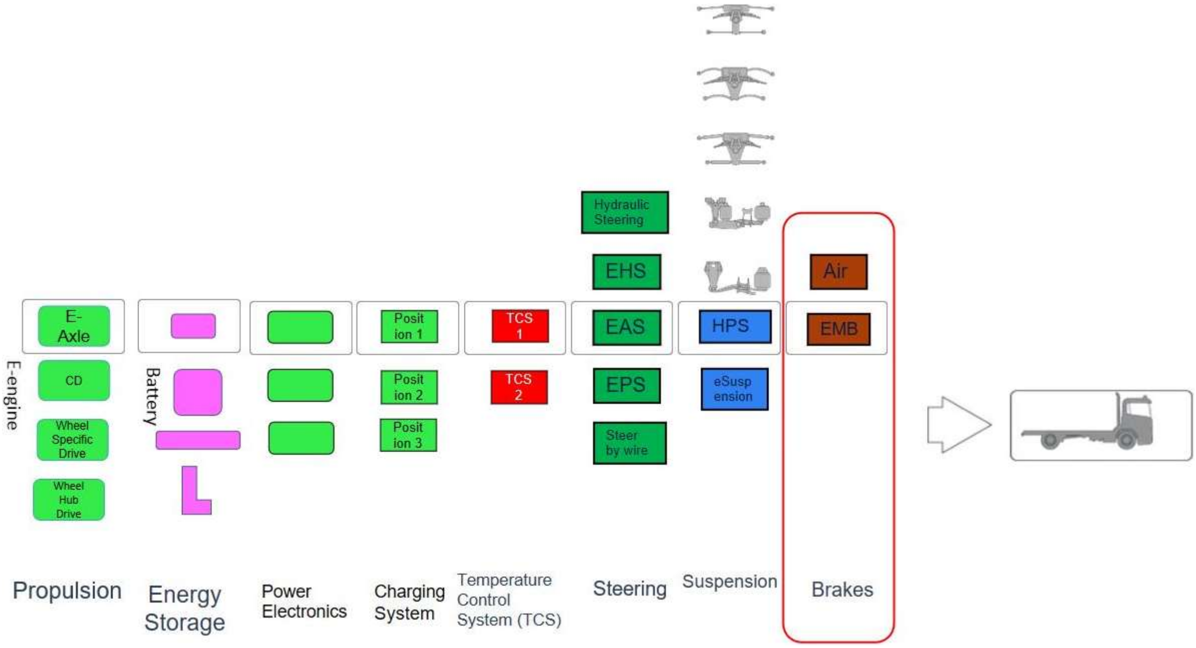


Figure 3.50 – Example of brakes in the Modular Toolbox

3.3.10. Trailer Control

Trailers connected to the trucks will also be affected by the electrification if the compressed air is removed. Currently the compressed air is commonly used for both suspension and brakes on semi-trailers. It then becomes important to drive the development of trailers which use non-compressed air brakes and suspension to ensure compatibility with the non-compressed air trucks. One solution to this could be to implement similar solutions as what is used on non-compressed air trucks to the semi-trailers. As mentioned earlier, this master thesis will not analyze the trailers, and this is therefore not regarded.

3.3.11. Power Take Off (PTO)

The PTO is used to power user's equipment which does not have its own source of power. It is commonly either connected to the engine, flywheel or the transmission of the truck as a source of power. The PTO can be offered to operate both while driving and standing still, depending on the customer need. Some examples of what this can be used for is to power the water pump on a firetruck, power the hydraulic lift on dumper trucks, power winches on tow trucks, etc. This functionality is not always needed by the customer and is therefore optional (Scania, 2019).

The electrification will affect the PTO since it is currently connected either directly to the ICE engine or transmission. It is as of now possible to connect a conventional mechanical PTO to the Central Drive concept but not to the other powertrain concepts. Therefore, there is some ongoing research to develop a new Electric PTO (E-PTO) which can be placed more freely on the truck since it is electrically powered. The E-PTO can be used to either supply electricity to the user's equipment or it can also be used to power a mounted motor or pump on the truck. As of now there are two ways of providing non-hydraulic E-PTO solution, through DC interface and AC interface. The trucks can be equipped with an AC interface by using an inverter and DC interface through use of Contactor Control Unit (CCU) (Engström, 2019). However, the research in this area is relatively small and thus the E-

PTO solutions may change with time. In *Figures 3.51-3.52* below the E-PTO placement on the truck can be seen. The small yellow box attached to the rear side of the purple battery. On the sides of the truck a hydraulic PTO can be seen where the big yellow box is the fluid tank and the smaller yellow box contains the inverter and pump.

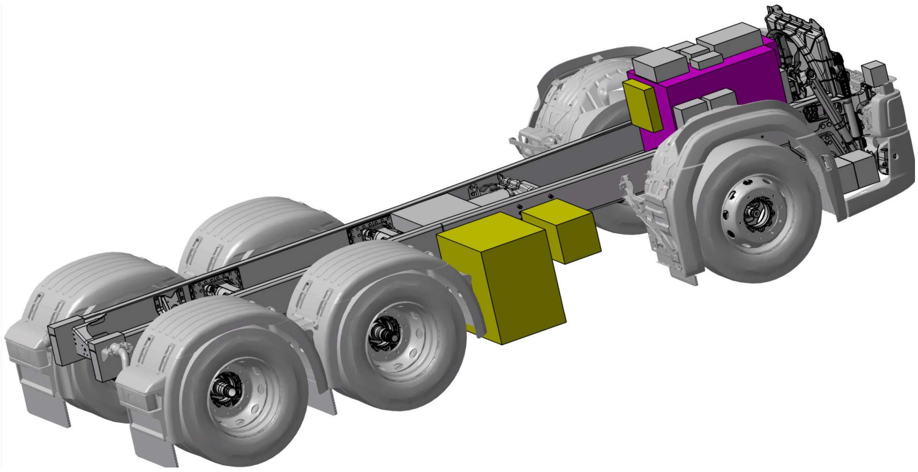


Figure 3.51 – PTO Placement on Layout

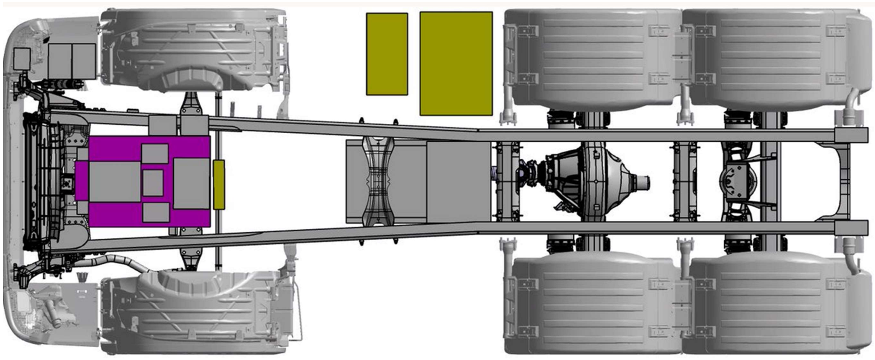


Figure 3.52 – PTO Placement on Layout

There are some benefits to the PTO system which arises when the truck becomes electrified. It now becomes possible to offer a PTO with power on demand which can help to greatly improve the energy efficiency since the motor must not be constantly running in comparison to an ICE truck where the engine must. This will in turn help to minimize operational costs and have less environmental impact. The noise level will also be greatly reduced which can help to improve the comfort for the user and other people in the vicinity since there is no engine constantly running. Since the electrified truck will not emit any exhaust gases when using the PTO on the electrified truck it will also help to improve the comfort for the user and other people in the vicinity since the air will be perceived as cleaner. An example of how the PTO performance series may look in the modular toolbox can be seen in *Figure 3.53* below.

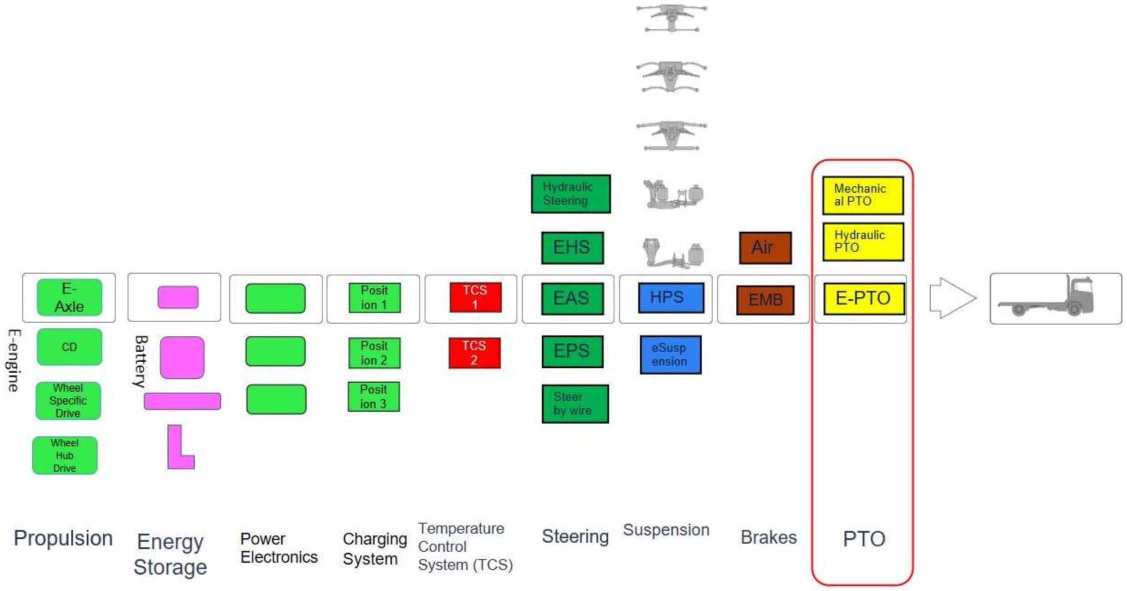


Figure 3.53 – Example of PTO in the Modular Toolbox

3.3.12. Electrical System

3.3.12.1. How it Currently Works at Scania

The electrical system connects all the electrical components on the truck, such as motors and 24V batteries, with control units and provides simple diagnostic. The system also provides wireless communication with the Scania service system. 24V batteries serve as starting batteries where they help to start the vehicle and they are also used to power the auxiliaries such as lights, pumps and compressors. Usually AGM and gel batteries are used as 24V batteries. (Scania, 2019)

On ICE trucks the electrical system is used to supply power to VCA components, which are 24V DC. In *Figure 3.54* below it can be seen how the electricity basically flows through the truck. The engine powers the alternator which in turn generates electricity and supplies it to the 24V batteries to keep them charged. This electricity is then taken whenever necessary to power VCA components.

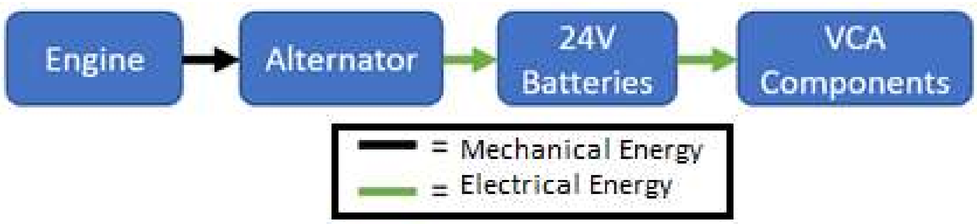


Figure 3.54 – Flow of Electrical Energy in ICE Vehicle

3.3.12.2. How it is Affected by the Electrification

For electrified trucks however this becomes more complex. The functional flow of electricity through conceptual electric trucks at Scania can be seen in *Figure 3.55* below. This information was gathered by analyzing existing conceptual ideas for electrified trucks at Scania. It can here be seen that electricity enters the trucks through the charging interface, get transformed in the charging box into high voltage DC and is then stored in the propulsion batteries. After this the electrical systems splits up into three groups of electrical sub-systems. One of these sub-systems is for the propulsion unit, which as of today is expected to be high voltage AC and therefore requires an inverter. Another subs-system is the VCA circuit as mentioned above. The existing low voltage solutions that Scania uses can be reused to minimize the amount of development work and minimize costs. Finally, the third electrical sub-system is the VCB circuit which delivers high voltage DC electricity to various components from the propulsion batteries.

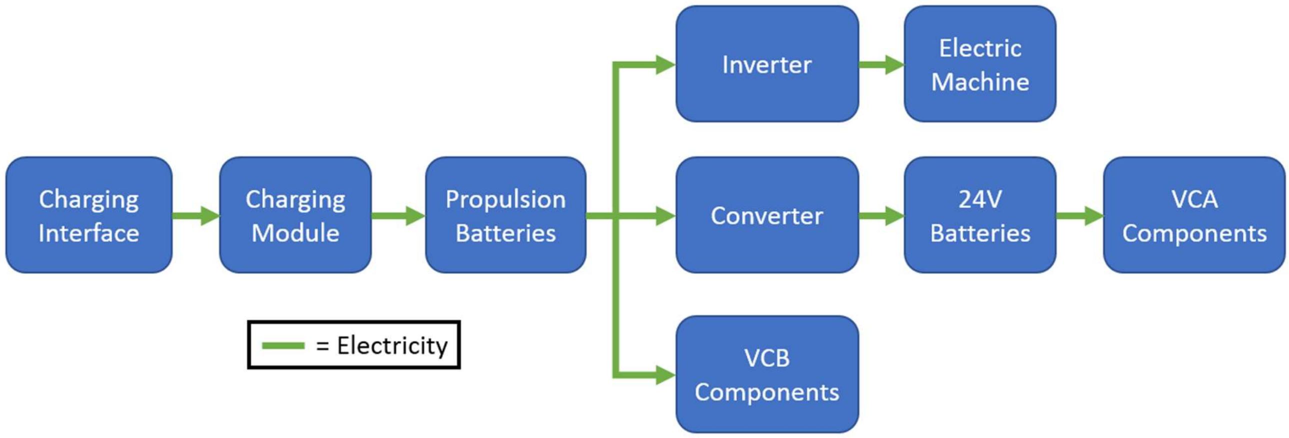


Figure 3.55 – Flow of Electrical Energy in BEV

Further in the future however the electrical circuits for the electrified trucks may look differently. It needs to be further analyzed whether it is necessary to have a low voltage VCA circuit. If all necessary components can be run directly on high voltage DC like the VCB then both the VCA converter as well as the 24V batteries can be removed from the truck. This would free up more space on the truck and may also decrease production costs since less components are necessary. However, it must first be analyzed how the production cost and size would differ for components if they transition from VCA to VCB before this can be concluded.

The two VCA batteries (24V) have previously been positioned on the side of the truck close to the mudguards. However, since it is beneficial to clear up this space and reserve it for the propulsion batteries it is therefore proposed to place the VCA batteries in the conventional air inlet position. This position will also have a short cabling distance to the power electronics which is desirable from a layout perspective. One drawback with this position is the difficult access to the battery. However, this can be solved by making it possible to open the surface beneath this area of the truck to access the batteries. Similarly, the batteries could be accessed by making it possible to open up the side of the bumper, allowing the user to easily reach the batteries if it is needed.

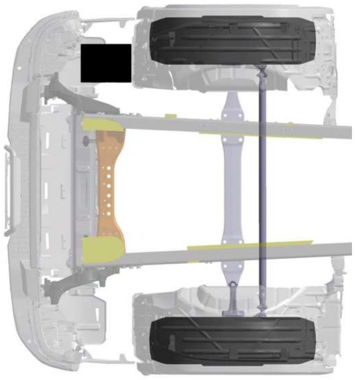


Figure 3.56 – VCA Batteries Placement

Figure 3.57 – VCA Batteries Placement

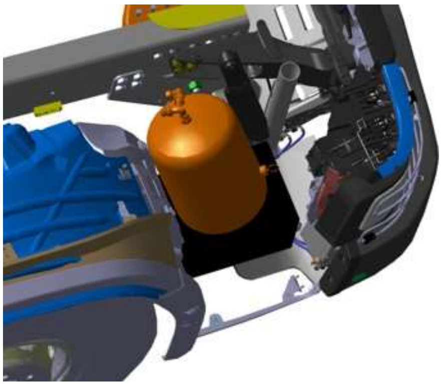


Figure 3.58 – VCA Batteries Placement

3.3.13. Cabling and Pipes

After analyzing all the affected systems mentioned above it was found that many of these will require cables and pipes to function properly. These then need to somehow be pulled along the truck to connect them to other necessary components. The cables and pipes which need to be pulled along the truck include VCA and VCB cabling, compressed air pipes and cooling pipes. To get an understanding of how much space needs to reserve for these cables and pipes an analysis was done on existing electric truck layouts within Scania. In these models the value of the necessary space was taken at the densest areas with the most amount of cables or pipes to ensure that enough space is always reserved. This is especially important since the amount of cables and pipes varies along the truck and gets also heavily affected by placement of components.

It was found that the VCA cabling will need an area of 64 mm in diameter reserved. The compressed air pipes will require up to 64 mm diameter reserved and the cooling pipes will need 20 mm diameter reserved to and from both the batteries and the inverter and 20 mm diameter to and from the powertrain. The amount of VCB cabling will vary depending on how many batteries are mounted to the truck. Each battery pack will need 25x50 mm thick cables going to the Xboxes since this cable will include both the positive and negative side. A similar VCB cable will also be required between the main Xbox and the inverter. VCB cables will also be necessary between the inverter and the propulsion unit, but since these are placed next to each other and thereby does not have to have a specific routing along the truck the cabling area does therefore not have to be reserved.

When analyzing how the cables and pipes could be pulled along the truck it was found that the inside of the frame was suitable since it stretched along the truck and would have no negative impact on the amount of free space for placing batteries. It was also found that placing the media and pipes inside the frame would help to simplify the routing since it would make it easier for some circuits to share a common path. The results can be seen in Figures 3.59 to 3.61 below. It can there be seen how the cross-sectional area will be reserved for VCA, VCB, compressed air and coolant pipes. It was decided to keep VCA and VCB on separate sides of the frame to ensure that these do not interfere with each other (Scania, 2019). The coolant pipe routing would have cold coolant on one side of the frame and warm coolant on the other to ensure that they don't negatively impact each other with heat. Similarly, the VCB cables should be kept in the same side of the frame as the warm cooling pipes since they might generate heat when used and risk therefore negatively impacting the cold cooling circuit pipes. Therefore, the left side of the frame is reserved for cool media, VCA cables and compressed air pipes and the right side for VCB and warm pipes. During this analysis it was also found that the cables need to be offset from the inner frame surface to reserve space for bolts which will be used to mount components to the frame. This can also be seen in *Figure 3.61* below. The cables should therefore also be flexible so that assembly and disassembly of components can be done when needed. This will however need a more thorough analysis to ensure that the cables are optimally placed from a production and maintenance perspective.

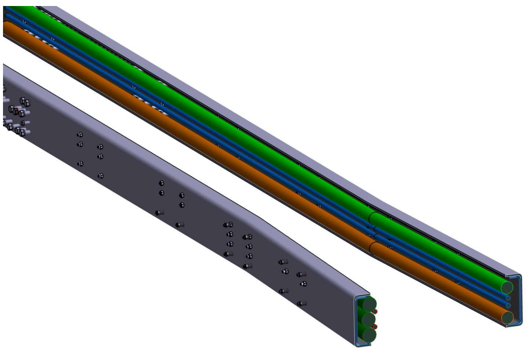


Figure 3.59 – Cross Sectional Picture of Routing Inside the Frame

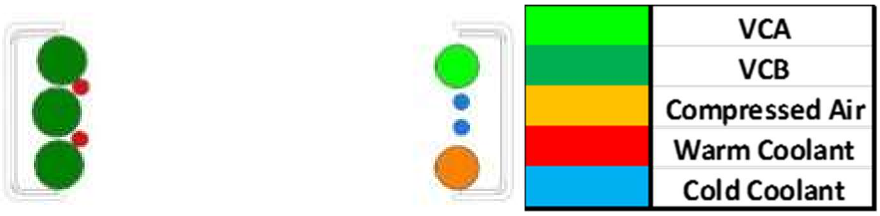


Figure 3.60 – Media and Pipe Inside the Frame

Figure 3.61 – Cross Sectional Picture of Routing Inside the Frame

3.4. Modified Modular Toolbox

In the Figure below an example of the proposed electric modular toolbox is presented. Here the additional necessary performance series and performance steps have been added which are required to build electric trucks. The performance series names, steps and solutions are only proposals and can be changed further if necessary. The goal with this toolbox is not to only offer one solution, but to offer different solutions so that the product can be tailored for each customer need. It is therefore necessary to analyze what the customer need is and connect it to how it can be fulfilled using the modular toolbox.

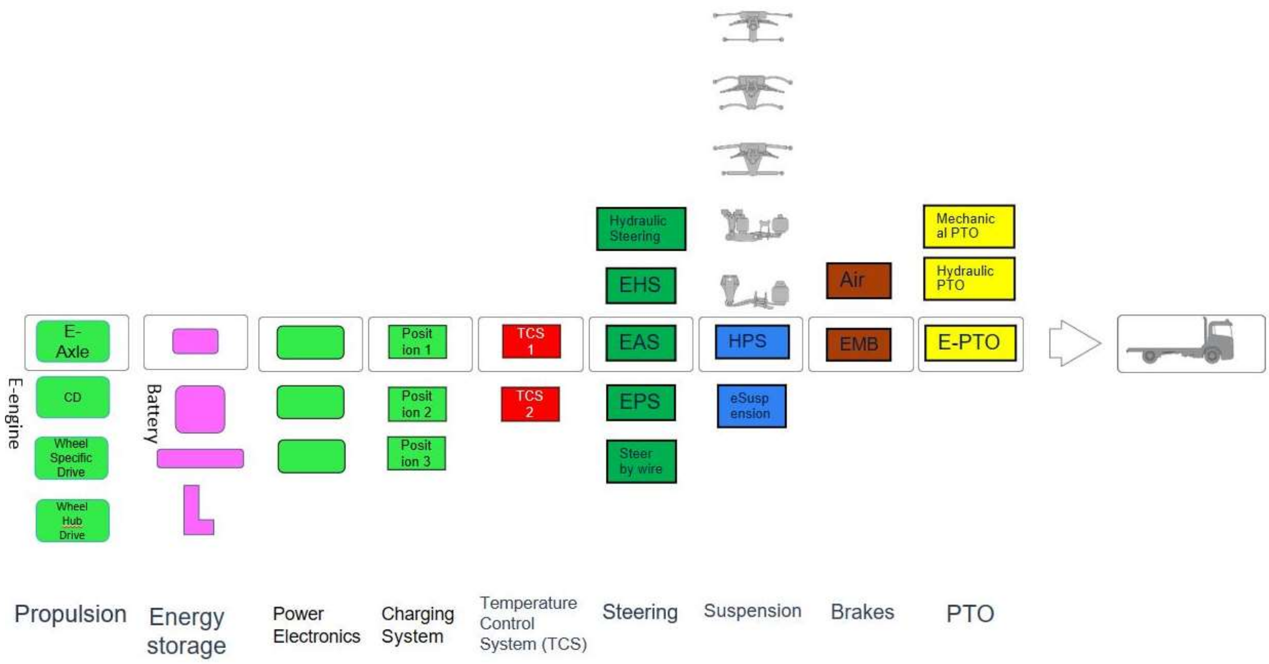


Figure 3.62 – Example of Electric Modular Toolbox

4. Battery Layout Analysis

In the previous chapter, it was shown the possible electrical alternative solutions for the components of the ICE powered truck and it was also shown the strategical place to place these components on the truck. Once all the necessary components are placed on the truck, the amount of free space available for the placement of batteries can be identified which can be seen in the *Figure 4.1* below. In the picture the difference between Central Drive and E-Axle when it comes to the free space available for batteries can be seen. As discussed earlier in the toolbox chapter, E-Axle enables the use of more batteries on the truck since Central Drive occupies the space between the frame in the central area of the truck.

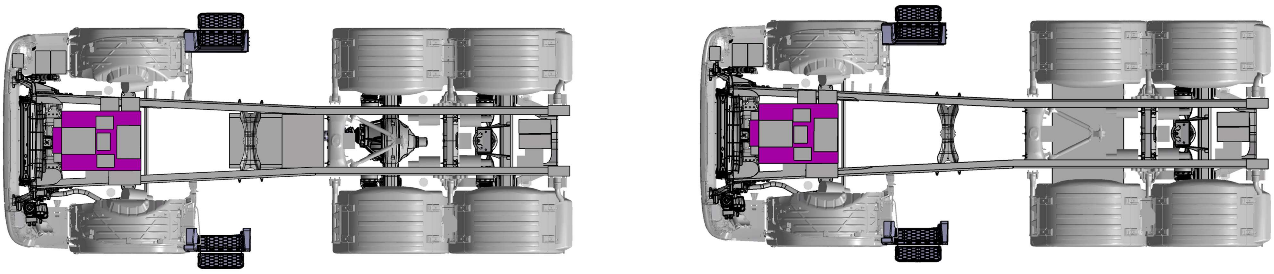


Figure 4.1: Available space for batteries on Central Drive and E-Axle

In this chapter a deep dive will be taken into the placement of batteries on the truck. In order to do so, few layout vehicles out of all the possible layout vehicles of Scania will be chosen and then assumptions regarding battery dimensions and their assembly on the truck will be discussed. Followed by discussing the approach towards the analysis and the observations gathered during the analysis. After which results of the analysis will be discussed which will give a lead into the conclusions chapter that will come afterwards.

The goal here is to propose layouts which are strategically designed from a function, relation and volume perspective. The layouts will also be strategically designed to utilize free space from increased axle distance.

4.1. Layout Definition

In order to understand the different layout vehicles available at Scania, it is essential to understand the definition of the layout. The truck layout can generally be described as the way in which components are placed on the truck in relation to each other. At Scania layout is used to show the space required on the truck to achieve its intended vehicle properties and functions (RTMX, 2019). To achieve this, it is good to thoroughly understand the customer need and then analyze how to place available solutions on the truck to fulfill the need.

It is especially important to strategically plan the layout on Scania's trucks to ensure that Scania's Modular Toolbox can be utilized to the fullest extent. However, this is not always possible. For example, Scania's current largest ICE, the V8, requires the R or S cabs to fit on the truck. It is also important to design the layout so that an increased axle distance, resulting in increased vehicle length and more free space, can be utilized for mounting additional equipment. Requiring too large incremental steps before the free space can be used for mounting additional equipment is an example of a poorly designed layout.

4.2. Chosen Layout Vehicles

Due to the limited time of the master thesis it is not beneficial to perform individual layout analysis for each wheel configurations since it would take much time. Instead it has been chosen to limit the layout analysis to only three wheel configurations which will represent the entire toolbox. These chosen wheel configurations will be referred to as layout vehicles. It thus becomes necessary to analyze which wheel configurations will be the most strategical to use as layout vehicles. The layout vehicles should represent a good spread of the entire portfolio of trucks that are possible through Scania's modular toolbox and should also represent different space limitations on the layout due to placement of the wheels, axles and other related components.

To strategically choose which wheel configurations to use, the most common wheel configurations were first retrieved and then grouped and compared to see which differed the most from each other. During this phase, it was found on a layout level that the front and rear of the truck usually had the same amount of space on the different wheel configurations. This was then regarded as a strategical area to place standardized components which are necessary for all trucks. It was then discovered that the middle of the truck, the area between the front axle and first driven rear axles, is a strategical area to place varying components since its size differs depending on the axle distance. This area is also known as Axle Distance (AD) area. After comparing the amount of free space in the AD area for different wheel configurations with a fixed axle distance, it was found that the wheel configurations 6x2, 6x2/4 and 8x4 differed the most from each other, as can be seen in *Figure 4.2* below. These are thus used as layout vehicles in the layout analysis.

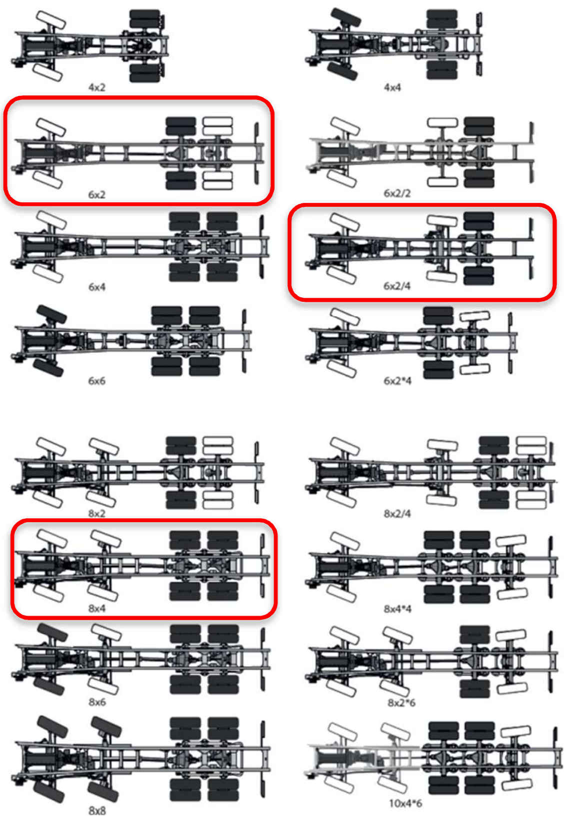


Figure 4.2 – Chosen Layout Vehicles

6x2 provides a good understanding of different layouts such as 4x2, 4x4, 6x4 etc.., where the AD area is free and can be fully utilized. 6x2/4 provides an opportunity to understand the complications on layout placed by having a steered axle in front the driven axle. Similarly, 8x4 provides an understanding of the complications on layout placed by having a double front axle. Therefore, these 3 layouts were chosen and for all these three layouts, a detailed battery layout analysis will be conducted for the minimum axle distance scenario, since these are the most space restricted layouts. Minimum axle distance for these layouts are 2950 mm for 6x2, 4050 mm for 6x2/4 and 4150 mm for 8x4. The intention is that if all the requirements on the layout can be fulfilled for these three layout vehicles with minimum axle distances, then it should also be possible to meet for all other axle distances.

Once this has been achieved, then the layout should be strategically designed to utilize additional free space when the axle distance is increased. It should thus not require too large incremental steps of the axle distance to allow mounting of additional components. The axle distance of 6x2 varies from 2950 mm to 6350 mm whereas 6x2/4 varies from 4050 mm to 5550 mm and 8x4 varies from 4150 mm to 6550 mm.

4.3. Battery Assumptions

It is essential to consider certain assumptions for batteries before doing a battery layout analysis. These assumptions include battery dimensions and battery assembly assumptions. Batteries are comprised of cells which can be either prismatic, cylindrical or pouch cells. Each cell type has its own advantages and disadvantages which is why different electric vehicle manufacturers chose different type of cells based on their priorities. For example, Tesla uses cylindrical cells whereas Scania is using prismatic cells which is why prismatic cells are being considered for this analysis.

These cells are then arranged in an order inside a module which has a voltage and kWh rating. Then based on the voltage need, certain number of these modules are connected in series or parallel inside a battery pack. Battery modules require cooling which is why certain space should be left for cooling plates inside the battery pack. Space should also be left for cables inside the pack which connects the modules. The assumptions for the battery modules, cooling plate and cables were taken from Scania and are considered while creating models of batteries. Battery pack will have a certain thickness for housing and insulation which was also considered which taking these assumptions. By considering all these assumptions, battery pack dimensions are derived for different form factors of batteries that are discussed in the toolbox chapter. An example can be found in the *Figure 4.3* below. (Cederlöf, 2019)

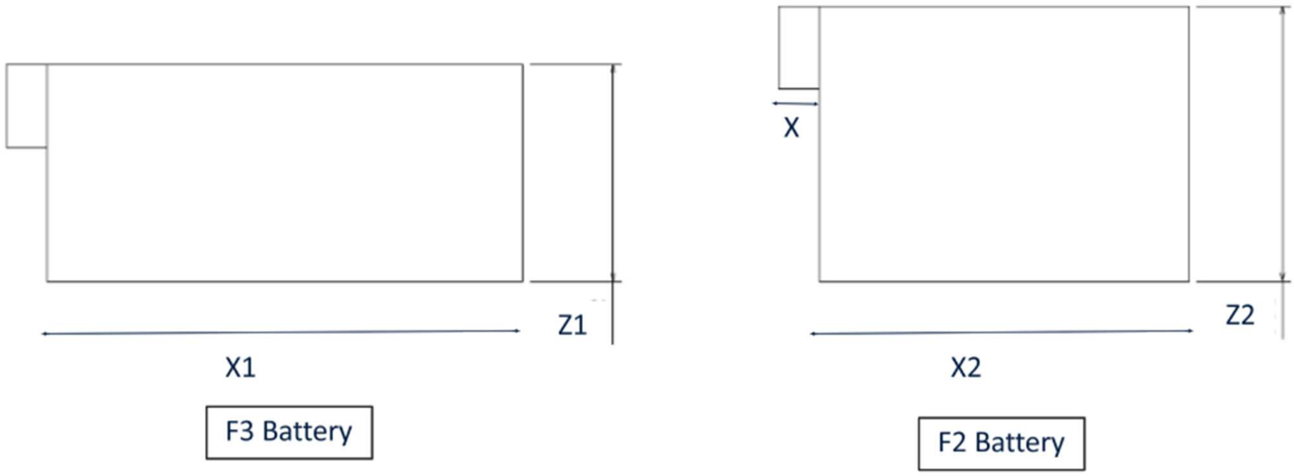


Figure 4.3: Battery Pack Dimensions

Dimensions of the battery will vary based on the form factor as can be seen in the picture where F2 battery is shorter in length than F3 but is taller in height. For all the different form factors, certain space (X) is reserved on any one side of the battery pack for junction box and cooling which is where all the cables, fuses, coolant pipes and other control elements of battery will be kept.

Once the battery pack dimensions are derived, there is a need to consider the assumptions for the assembly of the batteries. Batteries are assembled on to the truck with the help of brackets and need crash protection. Therefore, assumptions need to be considered for these. Also, when batteries are kept next to each other or next to another component, certain space should be left between them in order to allow the movement of the components while the truck is moving. Some of these assumptions can be found in the *Figure 4.4* below.

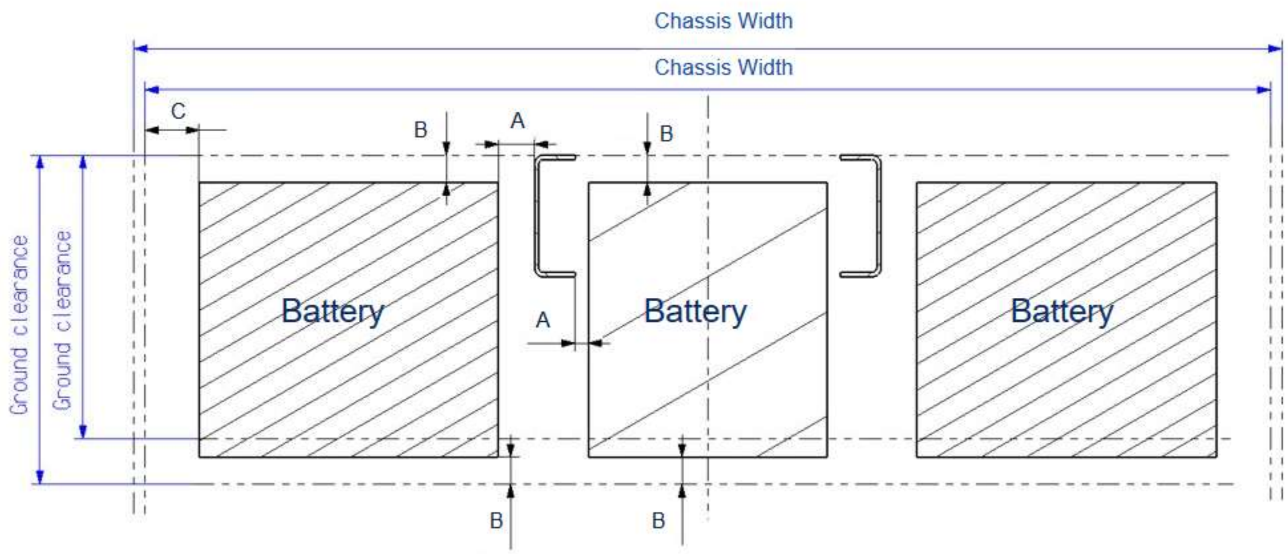


Figure 4.4: Battery assembly assumptions

In the picture 'A' is the assumption for the space to be left between the battery and the frame for the ease of assembly. 'B' is for brackets and 'C' is for crash protection. When multiple batteries are used on the truck, 25 mm gap will be left between them and between battery and other component for box shaped and split batteries (Arfert, 2019). Whereas, for complex shaped batteries that cover the entire chassis width, 150 mm gap on the side with junction box and 100 mm on the other side of the battery will be left. This gap is utilized for brackets that helps mount the batteries and for battery movement when the truck is in motion. (Peterson, 2019)

Ground Clearance and Chassis Width shown in the picture are some of the interfaces considered while placing the batteries. Ground Clearance is a measure between the top of the frame and the bottom of the components attached to the frame. Scania uses two different kind of ground clearances, one 'low' and one 'high' depending on the road conditions where the truck will be driven. 'Low' ground clearance means that the components are closer to the ground compared to 'high' ground clearance. By keeping the components within these ground clearances ensure that the components will never be harmed by irregularities on the road such as speed bumpers. Chassis Width is the legal demand set by the government for maximum chassis width and it varies depending on the country in which the truck is being driven which is why two chassis width are shown in the picture. While doing the assembly of batteries, it is always ensured to keep the batteries within the least Chassis Width dimensions thus satisfying the conditions of all the countries.

4.4. Approach

The approach for this analysis is described below. It is here described how the layout analysis will be performed by use of tools, delimitation to save time and process to ensure good results.

4.4.1. Software and Tools

The layout analysis will be performed in a CAD software since it will help to ease the work tasks by providing supportive functions and allows the work to be documented and distributed digitally at the company. Therefore, Catia V5 will be used since it is the main CAD software used in the field at Scania where the master thesis is performed.

Boxes will be created to represent the different form factors of batteries based on the dimensions and assumptions gathered through conducting various interviews with the engineers of Scania.

4.4.2. Delimitation

Due to the limited time of the master thesis it is important to work efficiently. Therefore, it has been decided to make some delimitations to the layout analysis to save time. The used delimitations used for the battery layout analysis are presented below.

Layout Vehicles:
As discussed earlier, due to time limitation only 3 vehicle layouts will be analyzed for battery analysis which are 6x2, 6x2/4 and 8x4.

Axle Distance:
As previously mentioned, Scania offers trucks with a span of varying axle distances. Since it will not be beneficial to perform individual layout analyses for each axle distance it has therefore been decided to strategically limit this. This will be done by first analyzing a truck with minimum axle distance and

ensuring that all necessary components fit. After this it will be proposed how to strategically utilize free space from increased axle distance. The presented solution from this will then be possible to share on all wheel configurations since the only things which will be added are additional batteries since all necessary components have already been added to the minimum axle distance layout analysis. Increased axle distance will most likely only be done to increase the energy storage capacity to increase the range of the trucks.

Propulsion:
As mentioned earlier out of all the possible electrical alternatives for propulsion, only two differed the most from a layout perspective. Therefore, battery layout analysis will be done for those two propulsions namely Central Drive and E-Axle.

Compressed Air:
Since this master thesis is focusing on a long-term scope it is therefore decided to focus the layout analysis on the benefits of removing the compressed air as mentioned earlier. In order to show the benefits of removing air and to provide a strategical layout for trucks with compressed air, layout analysis will also be done for trucks with compressed air. Therefore, battery analysis will be done for both compressed air and air free truck.

PTO:
E-PTO as a DC or AC interface will always have a space reserved for it on the layout as discussed in the toolbox chapter. Whereas, electric pump with wet kit as PTO will take more space on the layout and need to be considered while doing the battery layout analysis. Therefore, battery layout analysis will be done for the scenario with wet kit and scenario without.

Ground Clearance:
As mentioned earlier, Scania uses two ground clearances ‘high’ and ‘low’ based on the road conditions. Therefore, analysis will be done for both high and low ground clearances.

Articulated and Basic Trucks:
During the pre-study, it was found that the difference between articulated and basic trucks was minimal, as mentioned earlier in the report. The main difference was that the tractors or articulated trucks has a fifth wheel and shorter axle distance span. But since the area where the fifth wheel is located will not be used for mounting any components and since the analysis will be done for minimal axle distance as mentioned above it is therefore concluded that there will not be any benefits with performing individual analysis for the articulated and basic trucks. Therefore, it has been decided to only perform one layout analysis for both. The results from a single analysis will thus be applicable for both articulated and basic trucks.

Boarding Steps:
Most of the trucks require boarding steps just behind the front axles that provides access to the cabin or trailer controls that are placed in the back of the cabin. These boarding steps vary in their size based on the need. For a crew cabin which is usually used for fire trucks, where the cab is long and have a seating arrangement in the back of the cabin that allows more personnel to travel at the same time, boarding steps are wide and occupy the space in the axle distance region circled with red in the *Figure 4.5* below.

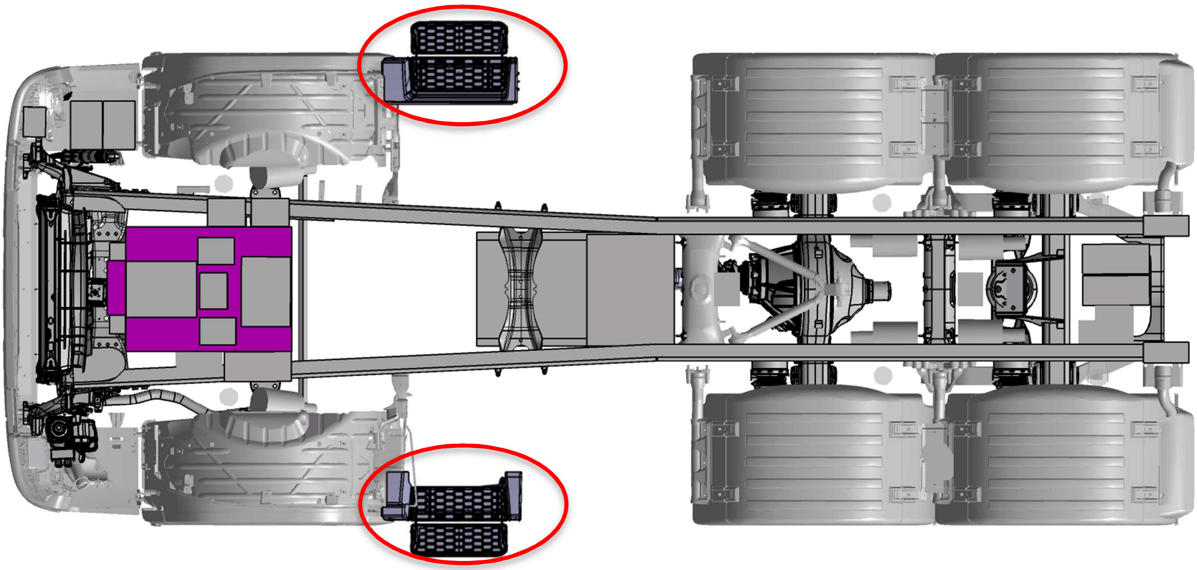


Figure 4.5: Boarding steps

As can be seen in the picture, these boarding steps negatively affect the placement of batteries on the truck which is why battery layout analysis will be done for both the scenarios with boarding steps and without.

4.4.3. Process

For each of the three vehicle layouts, battery layout analysis will be done for both the propulsion concepts Central Drive and E-Axle. For each of the propulsion concepts, analysis will be done for the scenarios with only compressed air, only PTO with wet kit, both compressed air and wet kit and a scenario where none are used. For each of these scenarios, analysis will be done for both the ground clearances low and high and for each of those analysis will be done with and without boarding steps. All in all, 96 scenarios will be conducted for the analysis and the major findings and results will be discussed in the following sub chapters. All the 96 scenarios can be found in the *Appendix 8.1*.

4.5. Discussion

The important findings from the battery layout analysis will here be discussed and analyzed. All the 96 scenarios will have a box battery placed in the engine region while trying to fit additional batteries on the truck based on the available space.

4.5.1. Layout Vehicles

In order to compare the three different layouts vehicles chosen, 6x2, 6x2/4 and 8x4, all the other factors are kept constant. Those factors are: all three layouts are shown with Central Drive as propulsion using non air suspension and brakes and with low ground clearance. When these factors are kept constant, the difference from a layout perspective can be seen for the three chosen layout vehicles in the *Figure 4.6* below.

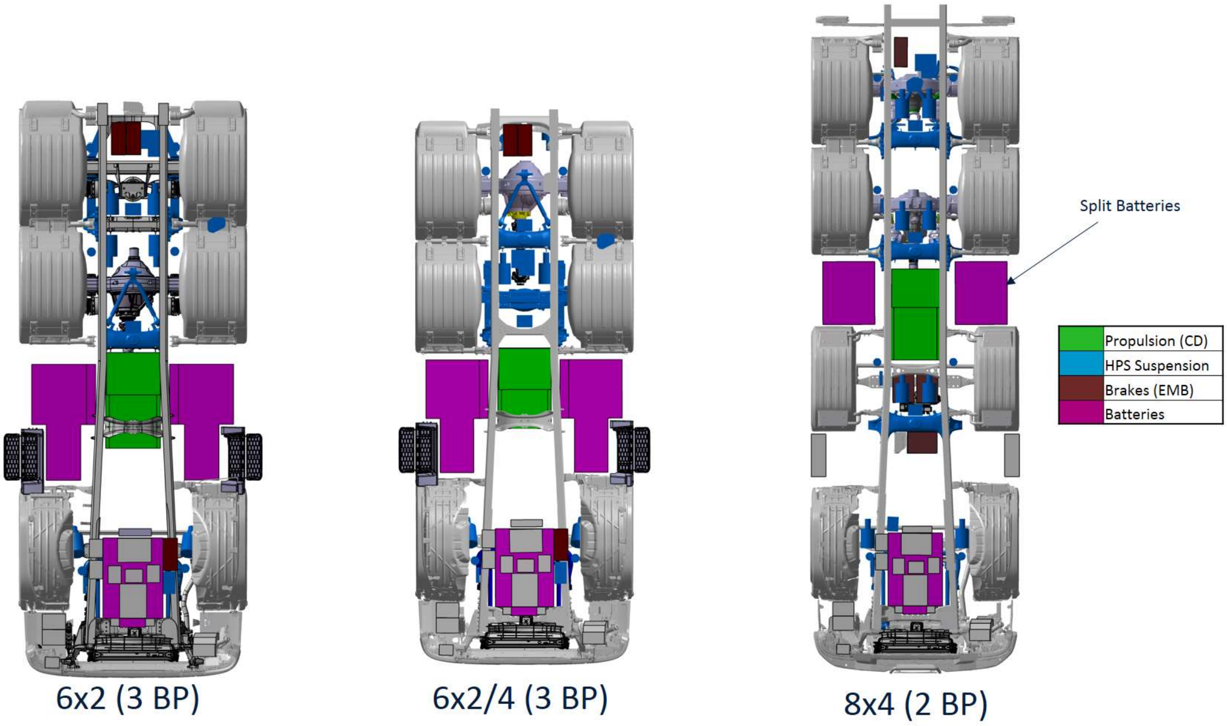


Figure 4.6: Layout Vehicles Comparison

It can be seen from the picture that 6x2 and 6x2/4 didn't differ much from a layout perspective and in both the cases, the same number of battery packs (3 BP) were possible to place on the truck. The main deviation can be seen for 8x4 where due to the battery assumptions that were considered, only 2 battery packs were possible to place on the truck, leaving a huge gap between the front axles that cannot be filled by a battery with current assumptions. It should be noted that the battery placed in the back of 8x4 is a split battery therefore should be counted as one.

It can also be seen from the picture that there is considerable amount of free space on all the three layouts that wasn't possible to fill with batteries. In the *Figure 4.7* below, the free space for the three layouts in terms of volume can be seen highlighted.

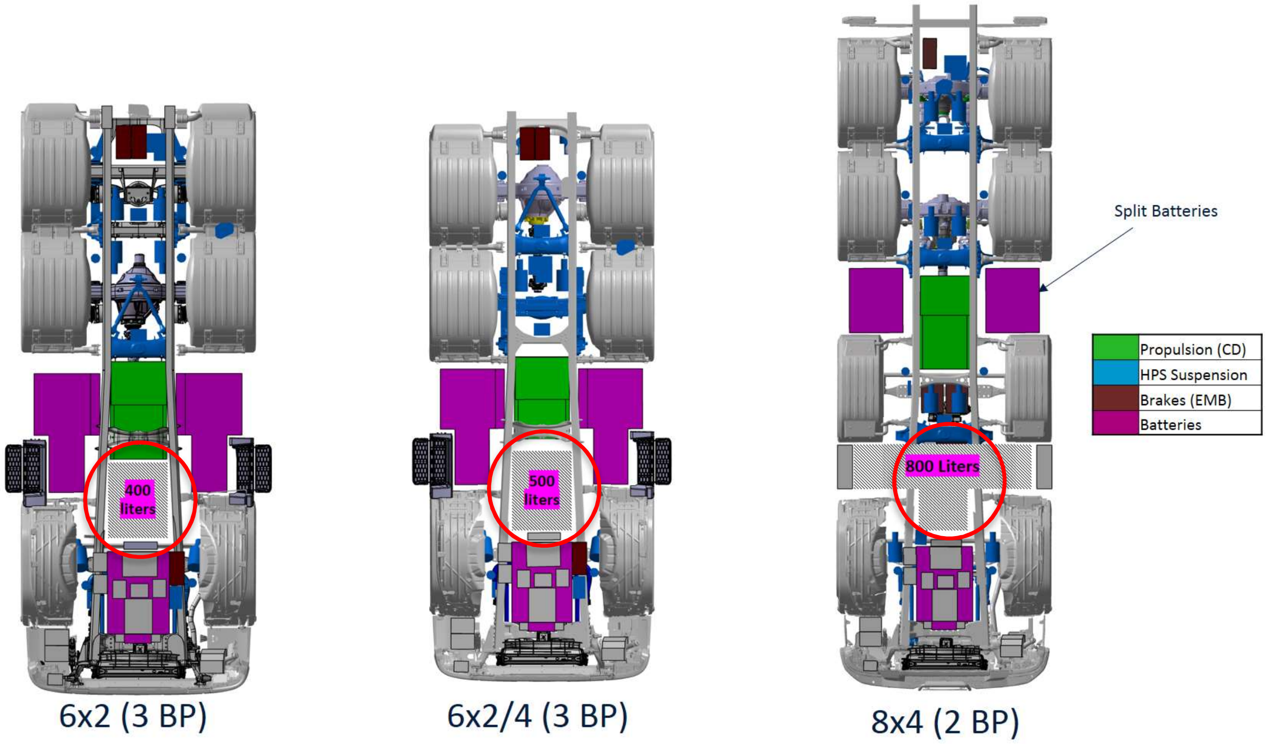


Figure 4.7: Extra Free Space Available

This extra free space that is available on the layout can be filled with batteries if the battery dimensions and assembly assumptions are altered.

4.5.2. Propulsion

It is already clear from the previous chapters that Central Drive (CD) constrains the use of batteries on the truck compared to E-Axle. This can be reaffirmed by placing batteries on the truck for the scenarios with different propulsions as can be seen in the *Figure 4.8* below. Again, in order to have a fair comparison, all the other factors are kept the same for the two layouts except for the propulsion.

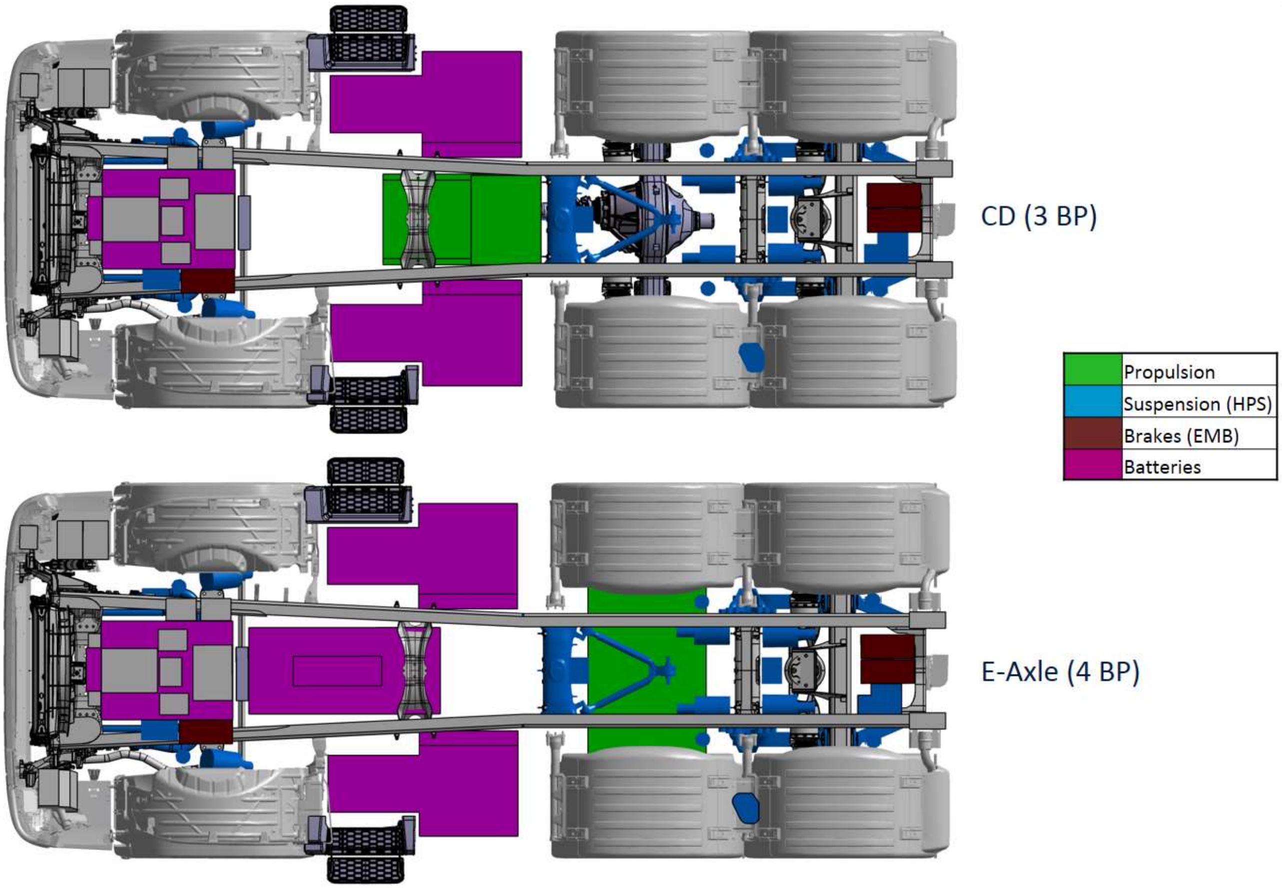


Figure 4.8: CD Vs E-Axle

It can be seen from the picture that E-Axle allows the placement of one extra battery compared to CD. This is logical since the CD occupied space on the area of the truck which was used to store batteries while the E-axle did not. Therefore, striving to use E-axle on the trucks can help to increase the energy storage on each truck.

4.5.3. Compressed Air

Removing compressed air from the truck provides the benefits of having energy efficiency and more free space on the truck. Therefore, in order to discover the layout benefits of removing compressed air, batteries are placed on a layout with compressed air and a layout without. This can be seen in the *Figure 4.9* below. It is to be noted that while using compressed air on the truck, air suspension is coupled with mechanical suspension in order to show the effects of mechanical suspension as well, which will be discussed further down in this chapter. Again, to reiterate, all the other factors are kept constant.

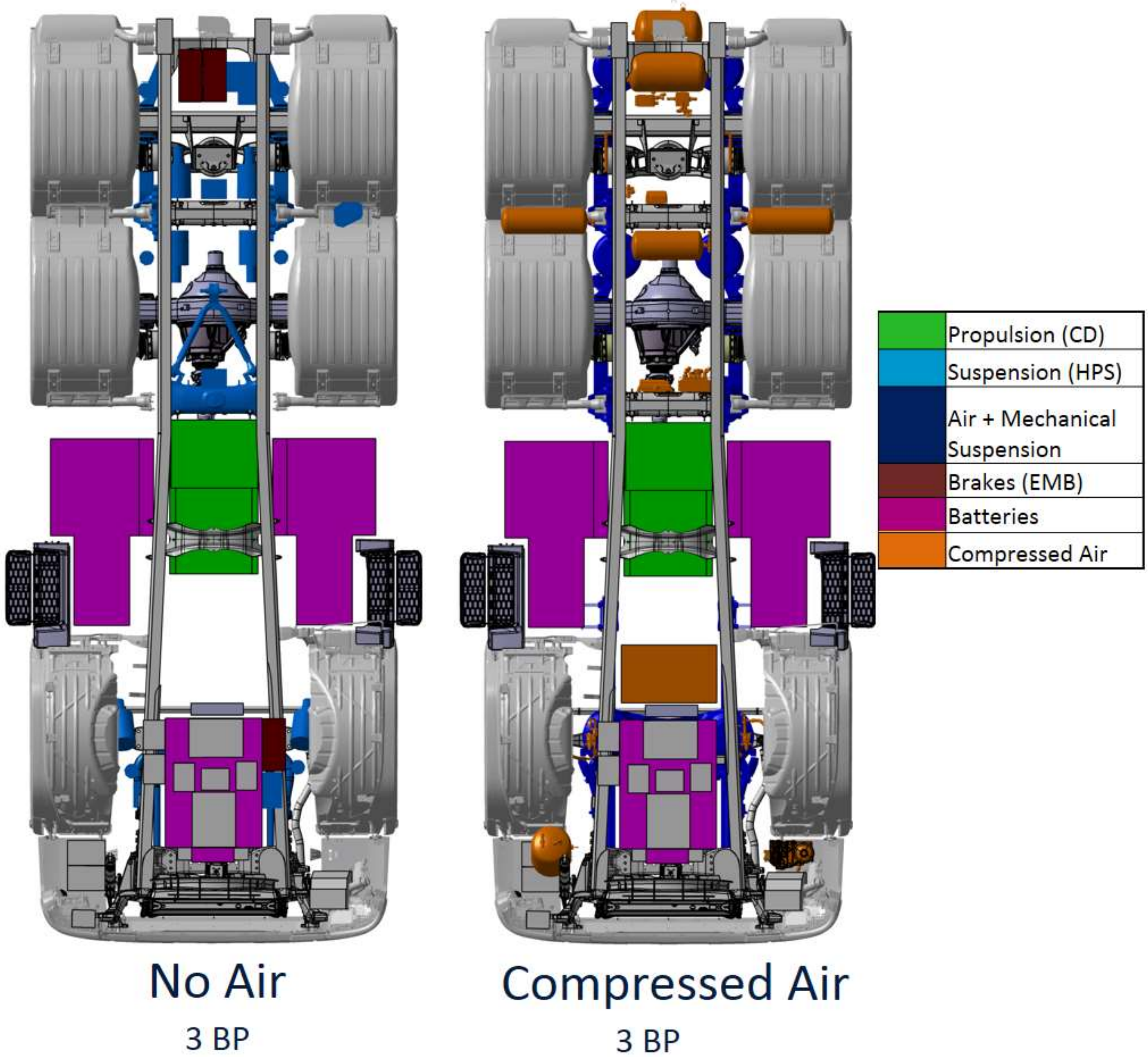


Figure 4.9: Compressed Air Vs No Air

It was found that the compressed air had little to almost no impact on the amount of batteries which could be placed on the truck. This was because the main constraint from a layout perspective placed by compressed by is the presence of an electric air compressor which can be placed in the free space pockets that couldn't be filled with batteries due to battery assumptions as discussed above. It should however be noted that it is still desirable to remove the compressed air from the truck since it has relatively low energy efficiency in comparison to non-air alternatives. Therefore, implementing air free alternatives such as HPS and EMB can results in decreased operational costs, increased range as well as lowered noise levels due to the removal of the air compressor.

4.5.4. Mechanical Suspensions

Due to the design of the mechanical suspension it limits the possibility to place suitable batteries on the layout. The reason for this was that the mechanical suspension is relatively long and occupies much space along the truck. This resulted in the mechanical suspension overstepping into the area where batteries were placed and sometimes clashing with these. The mechanical suspension also had another drawback which was that it had spring bolts on the ends of it which needed access in case of maintenance. Due to this, it was always necessary to leave space for these bolts to be accessed. This also resulted in limitation of the amount of batteries which could be placed on the truck, as seen in *Figure 4.10*. In order to highlight the problems caused due to mechanical suspension, E-Axle instead of Central Drive is shown in the picture.

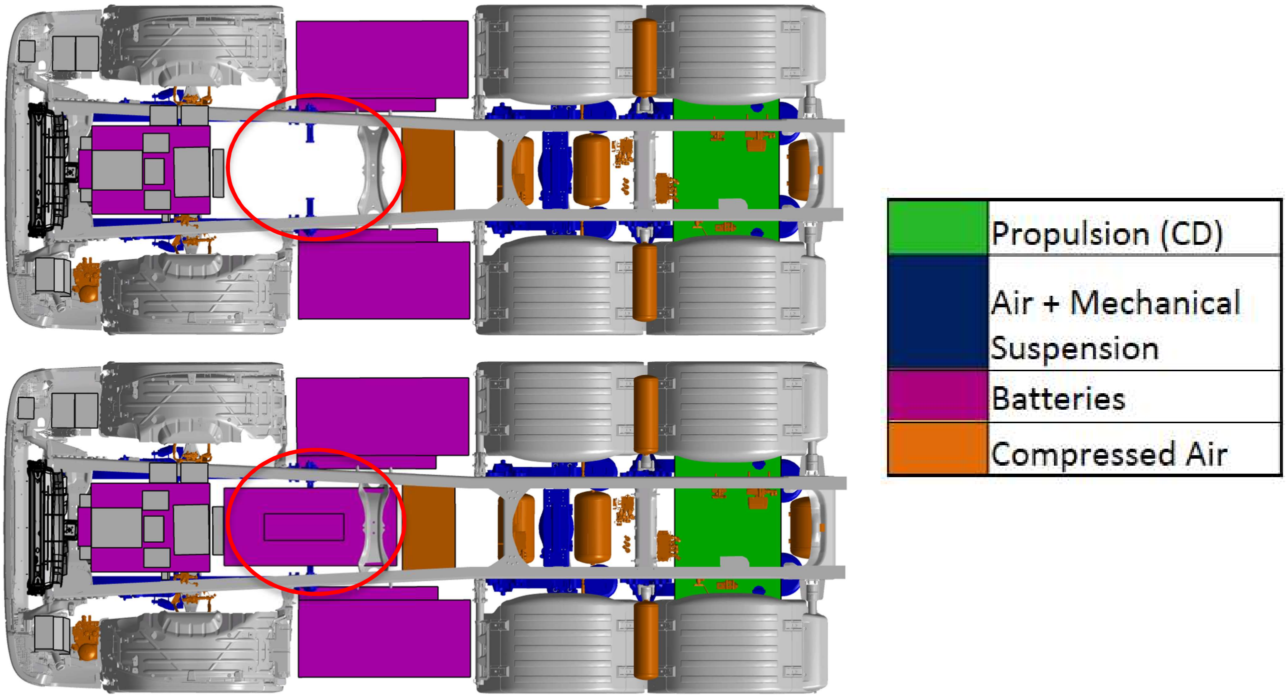


Figure 4.10 – Complications of Mechanical Suspension

It is therefore suggested to either strive towards using air suspension or HPS. However, this problem could also be solved by redesigning the mechanical suspension so that it is shorter and does not exceed the mudguard boundaries on the layout. The spring bolts which are used for mounting the mechanical suspension to the truck can also be redesigned so that they do not limit the amount of batteries that can be placed on the truck.

4.5.5. PTO with Wet Kit

As discussed earlier, for an electric truck PTO (Power Take Off) can be offered in the form of an electric pump with a wet kit which is a 200-liter hydraulic tank. This alternative of PTO will occupy considerable amount of space on the truck with the potential of effecting the placement of batteries. Therefore, to understand the impact of PTO, battery analysis was done with a layout having PTO and wet kit and a layout having no PTO, which can be seen in the *Figure 4.11* below.

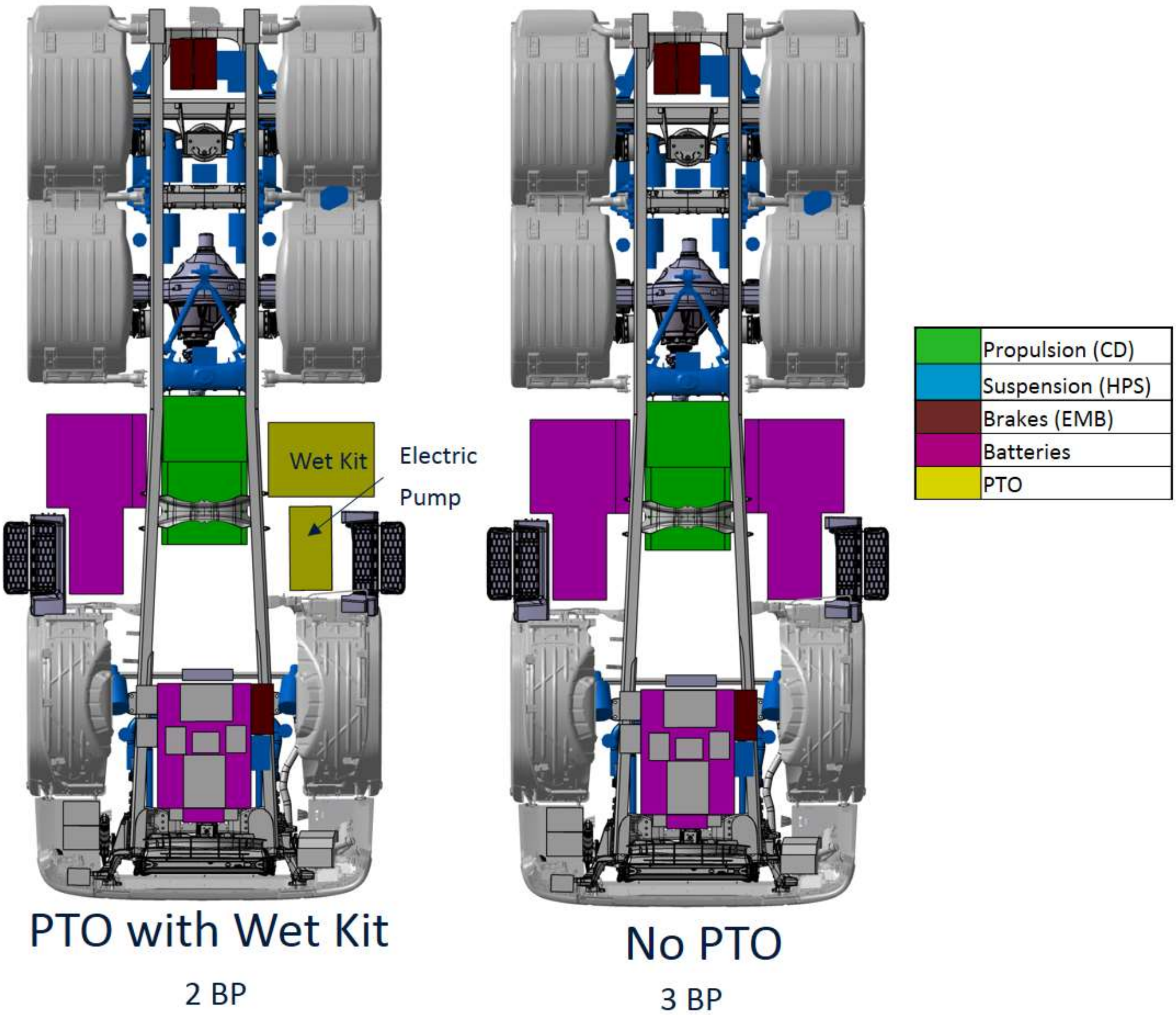


Figure 4.11: PTO with Wet Kit Vs No PTO

It can be seen from the picture that PTO and wet kit occupies the space that can used to store batteries thus limiting the amount of energy storage on board. It should be noted that an attempt was made to accommodate the electric pump and the tank in the free space available in front of the propulsion but due to the large size of the tank it wasn't possible to do so. Therefore, the tank is kept on the side of the truck which limited the usage of a battery as can be seen in the picture.

4.5.6. Ground Clearance

As discussed earlier, Scania uses two kinds of ground clearances, low and high. Low ground clearance enables the use of taller batteries whereas high ground clearance restricts it, which can be seen in the *Figure 4.12* below.

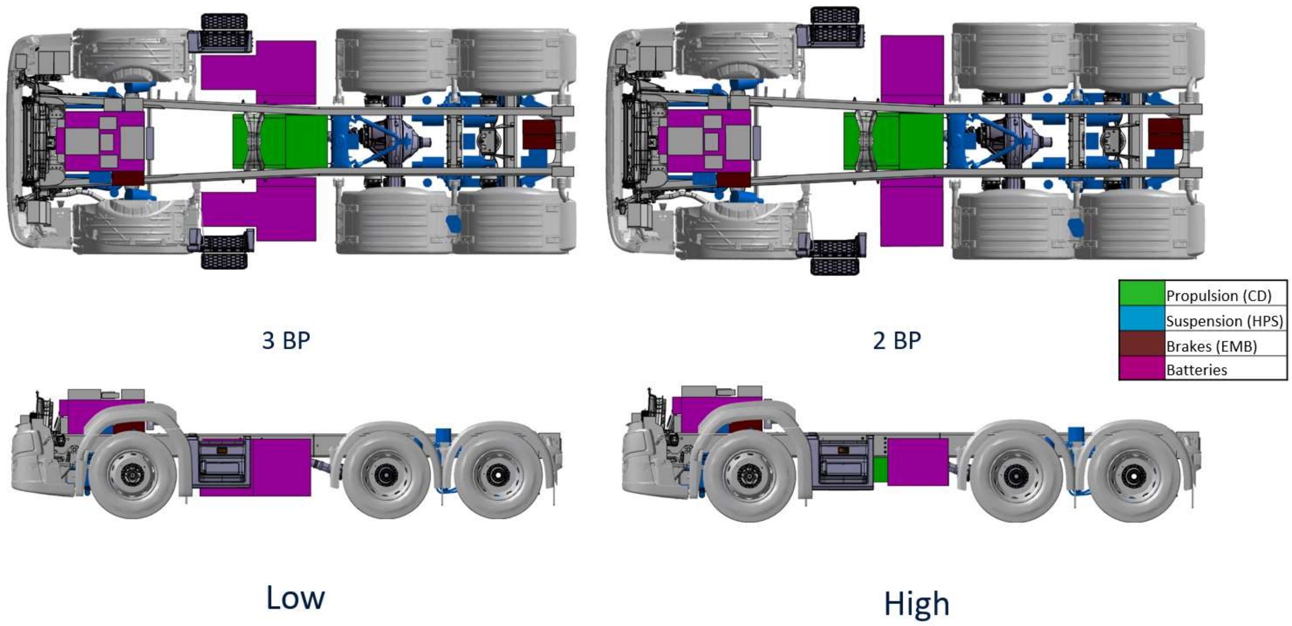


Figure 4.12: Ground Clearance

From the picture it can be seen that the low ground clearance enables the use of higher number of batteries compared to high ground clearance. This is due to the use of shorter batteries on the high ground clearance layout to ensure that the batteries will not be affected by the road conditions where there is a need for high ground clearance.

4.5.7. Boarding Step

From most of the pictures presented above it can be seen clearly that boarding steps occupy the space on the truck that could have been used for the placement of batteries. In order to see how much effect, the boarding steps have on the placement of batteries, battery layout analysis was done with a scenario with boarding step and one without, which can be seen in the *Figure 4.13* below.

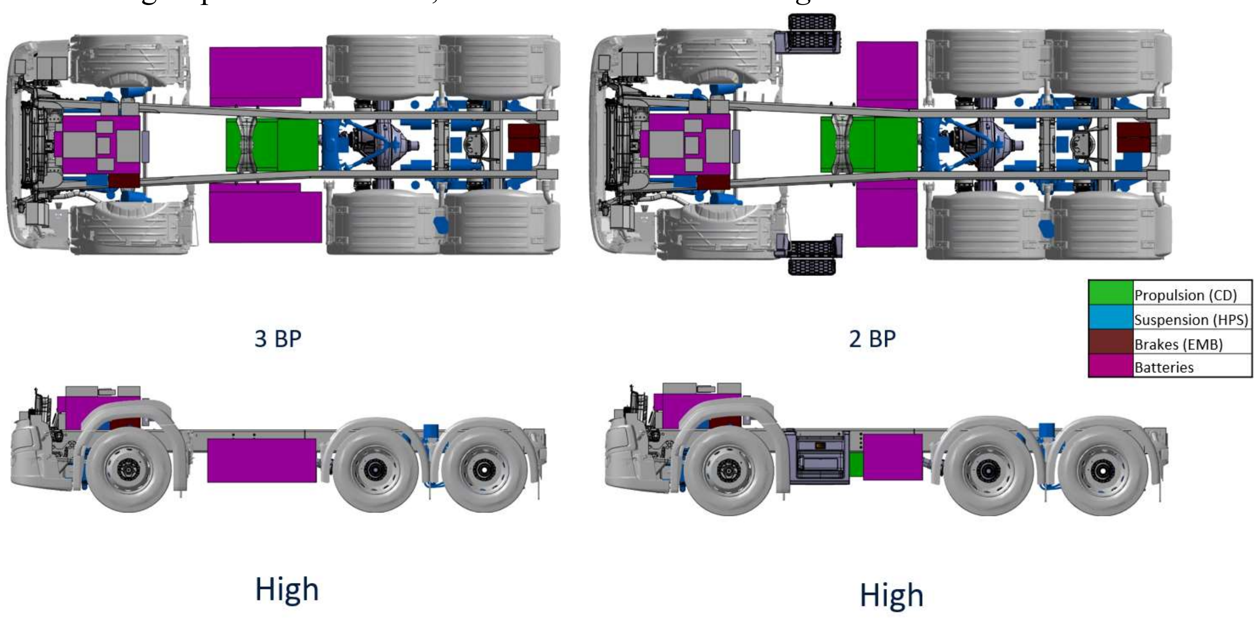


Figure 4.13: Boarding Steps

In order to show the effects of having a boarding step on the battery placement, high ground clearance scenario is chosen since it represents the complications of boarding steps in a better way. From the picture it can be seen that boarding steps limits the use of batteries on the truck.

There is a possibility to change the design of boarding steps to enable the use of more batteries on the truck. This can be done in multiple ways; one way is to integrate the steps into batteries thus making batteries that also work as boarding steps. Another way is to make the boarding steps foldable, that way they can be unfolded when there is a need to access them and the remaining time, they stay folded, thus not affecting the placement of batteries. This can be achieved by connecting the boarding steps to the door of a crew cab, that way when the door is opened, the steps will be unfolded enabling the customer to get into the cabin.

4.5.8. Frame

Frame used at Scania has been optimized for the usage of engine in the front which is why it has a bent shape in the front. Because of this bent shape, this frame is not ideal to use for an electric truck if the objective is to have more energy storage on the truck. In the *Figure 4.14* shown below, it can be seen that the bent shape restricts the use of batteries, especially in the case of 8x4 which is shown below.

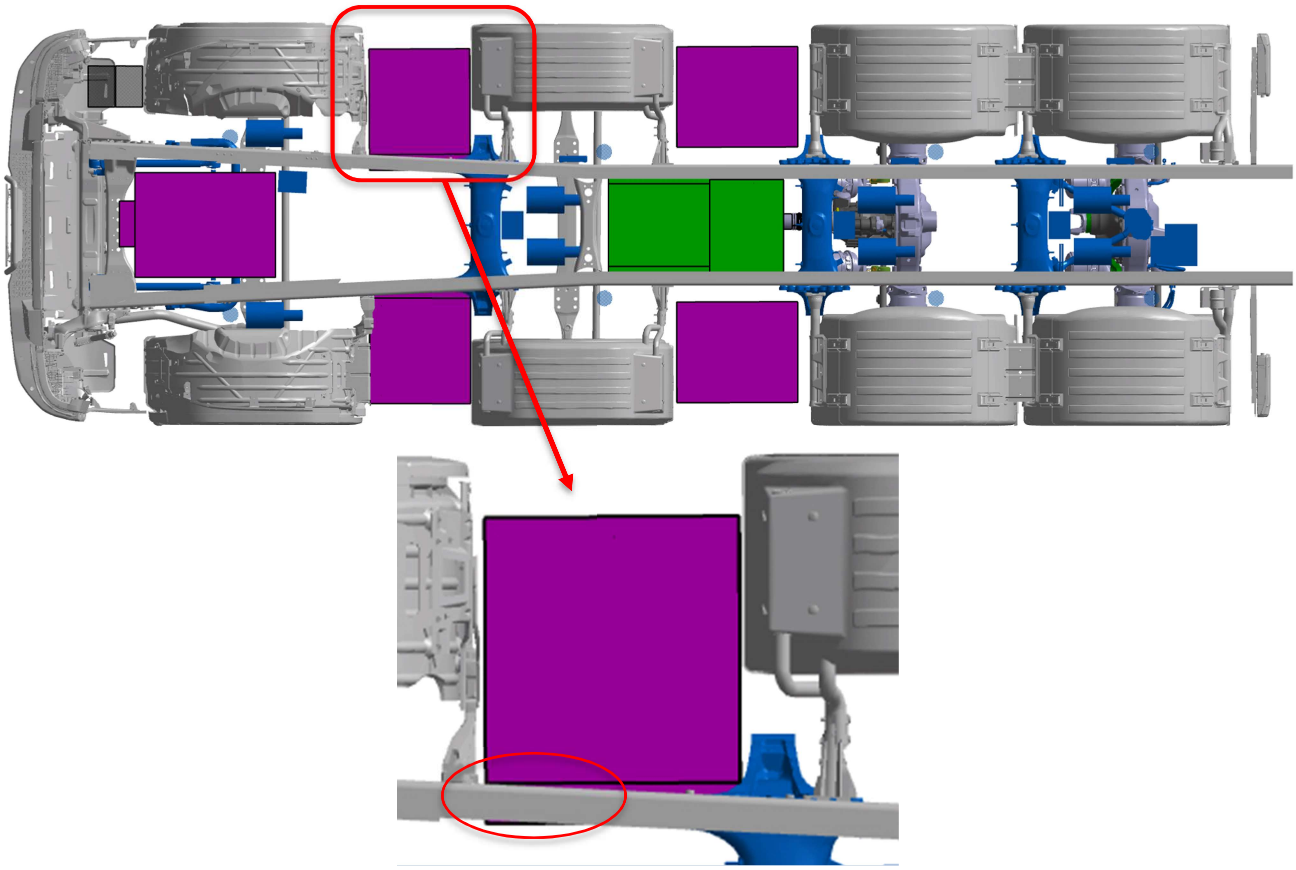


Figure 4.14 – Effect of frame shape and battery assumptions

It can be seen that even if the smallest battery which is the split battery, is used between the two front axles of 8x4, batteries almost collide with the frame. This is not ideal, since there is a requirement of having certain gap between frame and battery to enable the ease of assembly. Therefore, frame shape needs to be adapted for electric vehicles and more research needs to be done to find the optimal shape of the frame that is best suited for electric vehicles. This collision between frame and battery is also caused due to the battery assumptions that are considered, especially the assumption for crash protection. If this assumption is changed, then there is a possibility that this battery can be used in this scenario. To conclude, frame shape needs to be adapted for electric vehicles or battery assumptions need to be reconsidered.

4.5.9. JA packaging

The JA distance is the distance between the driven axle and the rear end of the truck, as visualized in *Figure 4.15* below. The JA distance is today not used for packaging components and is reserved for customers. However, using this area could help increase maximum energy storage on a layout. Therefore, it would be beneficial to look into if this area to see if it could be utilized for the placement of batteries. This is however possible when it is not used by the customer for placing other components and when there is no risk that it would collide with a trailer connection during sharp turning.

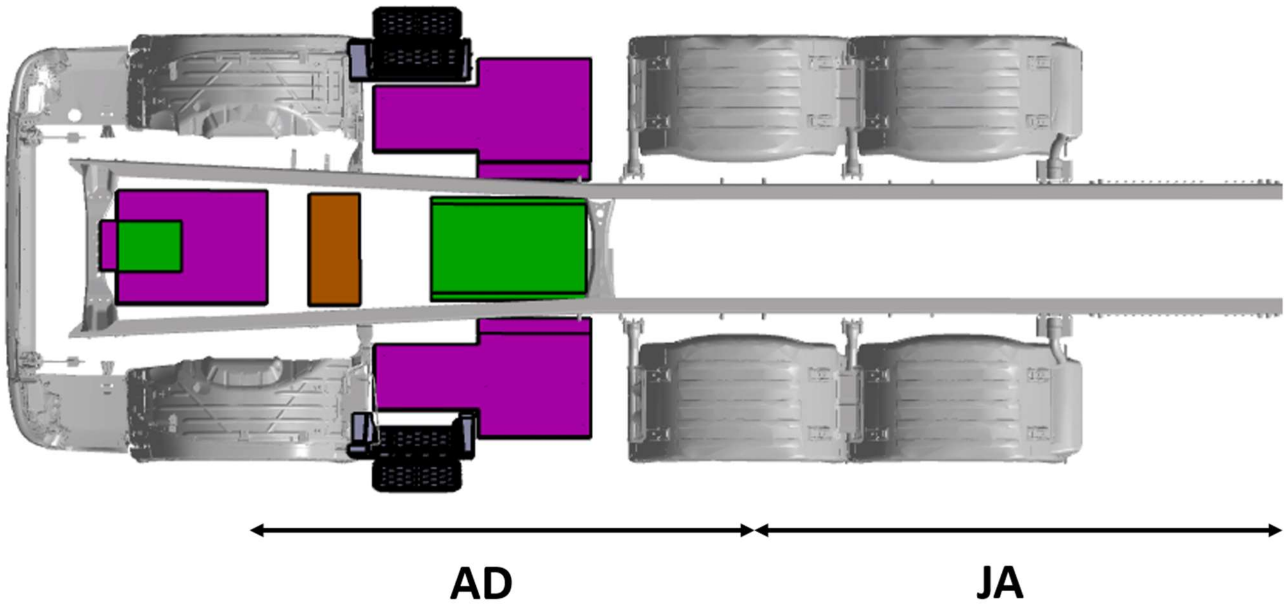


Figure 4.15 – AD and JA Dimensions on Trucks

4.6. Results

The number of battery packs which could be fitted onto each minimum AD layout in the 96 scenarios mentioned above were compiled into the *Table 4.1* below. Colors were used in the boxes to help differentiate between the different values. The green color represents 4 battery packs, yellow represents 3 battery packs, light red represents 2 battery packs and dark red represents 1 battery pack.

	6x2		6x2/4		8x4	
E-Axle	With Rear Boarding Setps	Without Rear Boarding Setps	With Rear Boarding Setps	Without Rear Boarding Setps	With Supporting Leg	Without Supporting Leg
Low GC:						
None	4	4	4	4	3	3
Compressed Air	4	4	3	3	3	3
Hydraulic PTO	3	3	3	3	2	2
Both	3	3	2	2	2	2
High GC:						
None	3	4	3	4	2	2
Compressed Air	3	4	3	3	2	2
Hydraulic PTO	2	3	2	3	2	2
Both	2	3	2	2	2	2
CD						
Low GC:						
None	3	3	3	3	2	2
Compressed Air	3	3	3	3	2	2
Hydraulic PTO	2	2	2	3	1	1
Both	2	2	2	3	1	1
High GC:						
None	2	3	2	3	2	2
Compressed Air	2	3	2	3	2	2
Hydraulic PTO	2	2	2	2	1	1
Both	2	2	2	2	1	1

Table 4.1 – Number of Battery Packs per minimum AD Scenario

The table reiterates the fact that E-axle enables the use of higher number of batteries compared to Central Drive as can be seen by comparing the top half of the table with the bottom half. It can also be seen that having compressed air doesn't affect the energy storage. It was also found that the few scenarios where the compressed air layout had negative impact on the amount of batteries which could be placed on the truck was caused by the mechanical suspension as mentioned above.

4.7. Axle Distance Increase

Until now, battery placement for minimum axle distance of various layout vehicles was analyzed. In this chapter, the approach towards battery placement for axle distance increase will be analyzed. The idea behind doing an axle distance increase analysis is to figure out a pattern for the approach towards battery placement for increased axle distances that will be applicable for all axle configurations.

4.7.1. Approach

In order to do the battery placement for axle distance increase, one scenario for each vehicle layout was chosen and axle distance was increased for the purpose of only placing additional batteries. This analysis was done for both high and low ground clearances. For representation, only 8x4 low ground clearance with no air and Central Drive will be represented here for axle distance increase approach, whereas axle distance increase for other layouts can be found in the *Appendix 8.1*.

In the previous chapters it was already seen the how many batteries can be placed on low ground clearance 8x4 layout with no air, 2 Battery Packs, which is shown below in the *Figure 4.16*.

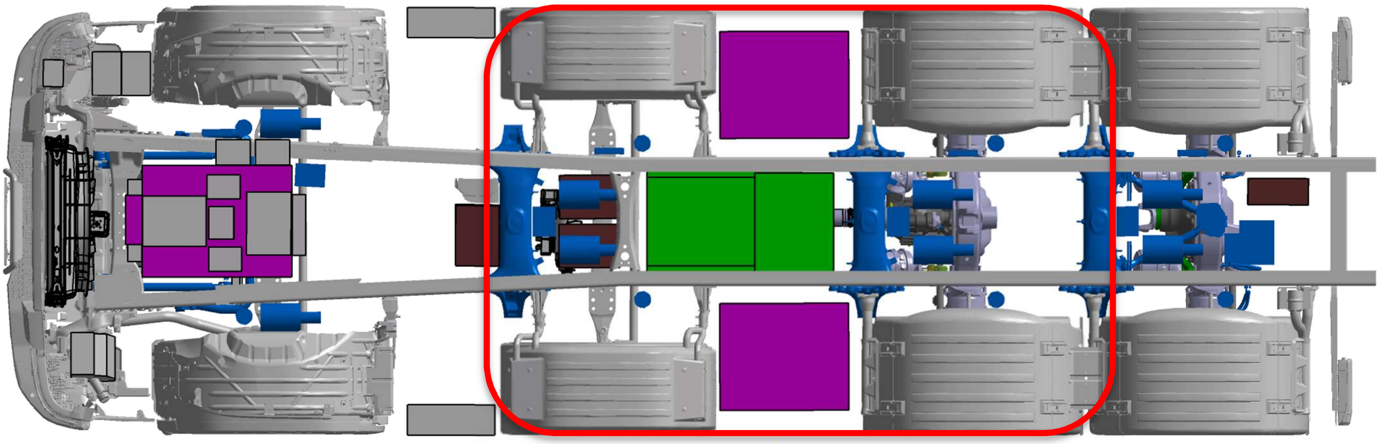


Figure 4.16: 8x4 Battery Placement for No air, Central Drive

It is to be noted that split batteries are used in the back, which is why they count as one battery, thus bringing the count to 2 batteries for minimum axle distance scenario. As discussed earlier, batteries weren't possible to place between the two front axles due to the bent shape of the frame and the battery assumptions that were considered.

In the *Figure 4.16*, Axle Distance region is highlighted in red, since this is the region where additional batteries will be added when the axle distance is increased. The approach for axle distance increase for 8x4 can be found below in the *Figure 4.17*.

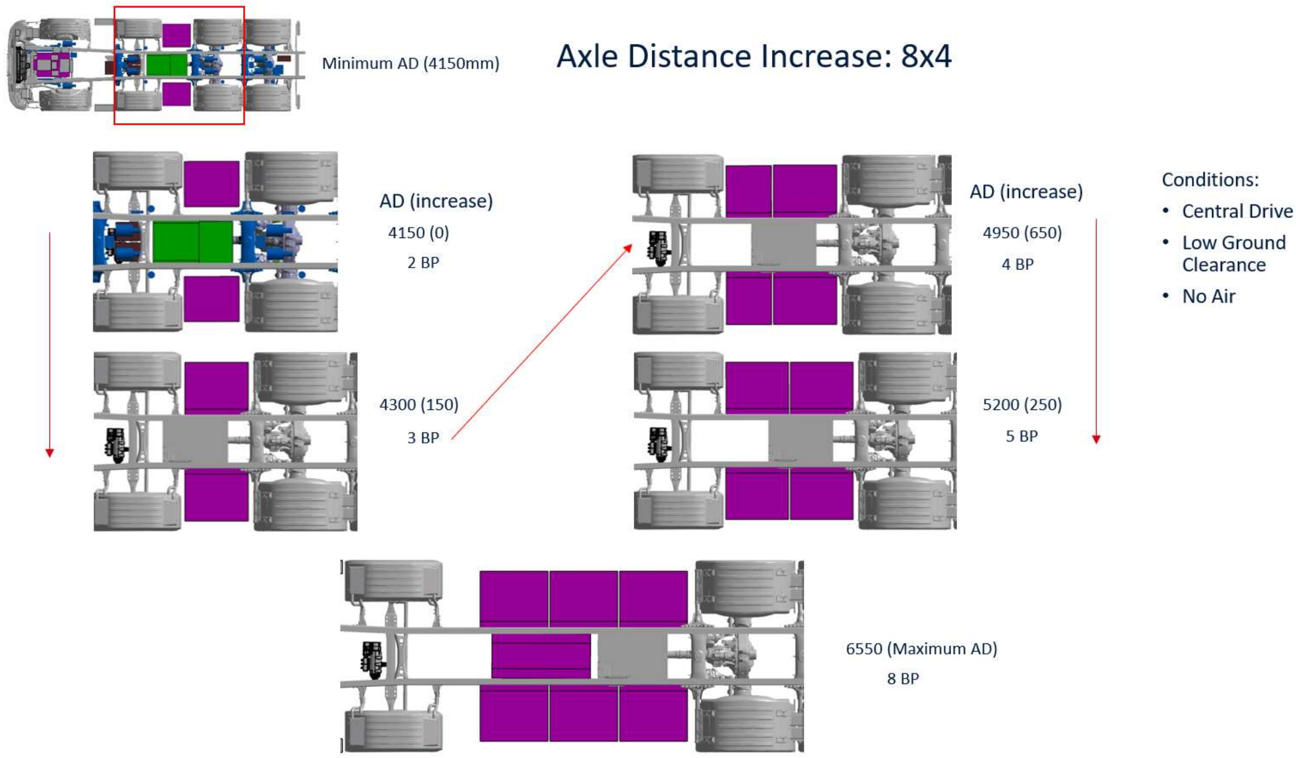


Figure 4.17: Axle Distance Increase Approach

Since axle distance increase is done in order to increase the amount of free space, it had to follow certain pattern of increase which can be seen in the picture. Initially to add one more battery to the minimum axle distance case, AD has to be increased only by 150 mm this is because in the minimum AD case, there was already some free space between the axles which wasn't used by batteries. There is no pattern to be discern by this.

Pattern starts with the next increase which was by 650 mm, this is the least amount that had to be increased since split batteries are the smallest of the batteries available, therefore the energy storage increase starts with those. Therefore, for 650 mm, split batteries are added, bringing the total count of batteries to 4. The next step is to convert this split batteries to full box batteries which requires an addiional axle distance increase of 250 mm, by which split are converted to box batteries and the total count increases to 5. This pattern is repeated until the maximum axle distance is reached, pattern being first step: increase the AD by 650 mm to accommodate split batteries. Second step: increase the AD further by 250 mm to convert the split into box batteries.

This pattern can be applied to all the other vehicle layouts and axle configurations to increase the energy storage through increase of axle distance. In the picture it is also shown the maximum axle distance case where through following this pattern, more batteries were added and an additional battery was added in between the frame, bringing the total count to 8 battery packs.

4.7.2. Discussion

4.7.2.1. Complex Shaped Batteries

Complex shaped batteries especially the ones that are shaped as U or W, that goes around the frame, can be used in the place of box shaped batteries to increase the amount of energy storage for a shorter axle distance. This was observed for 8x4 in the case of axle distance increase scenarios for high ground clearance as can be seen in the *Figure 4.18* below.

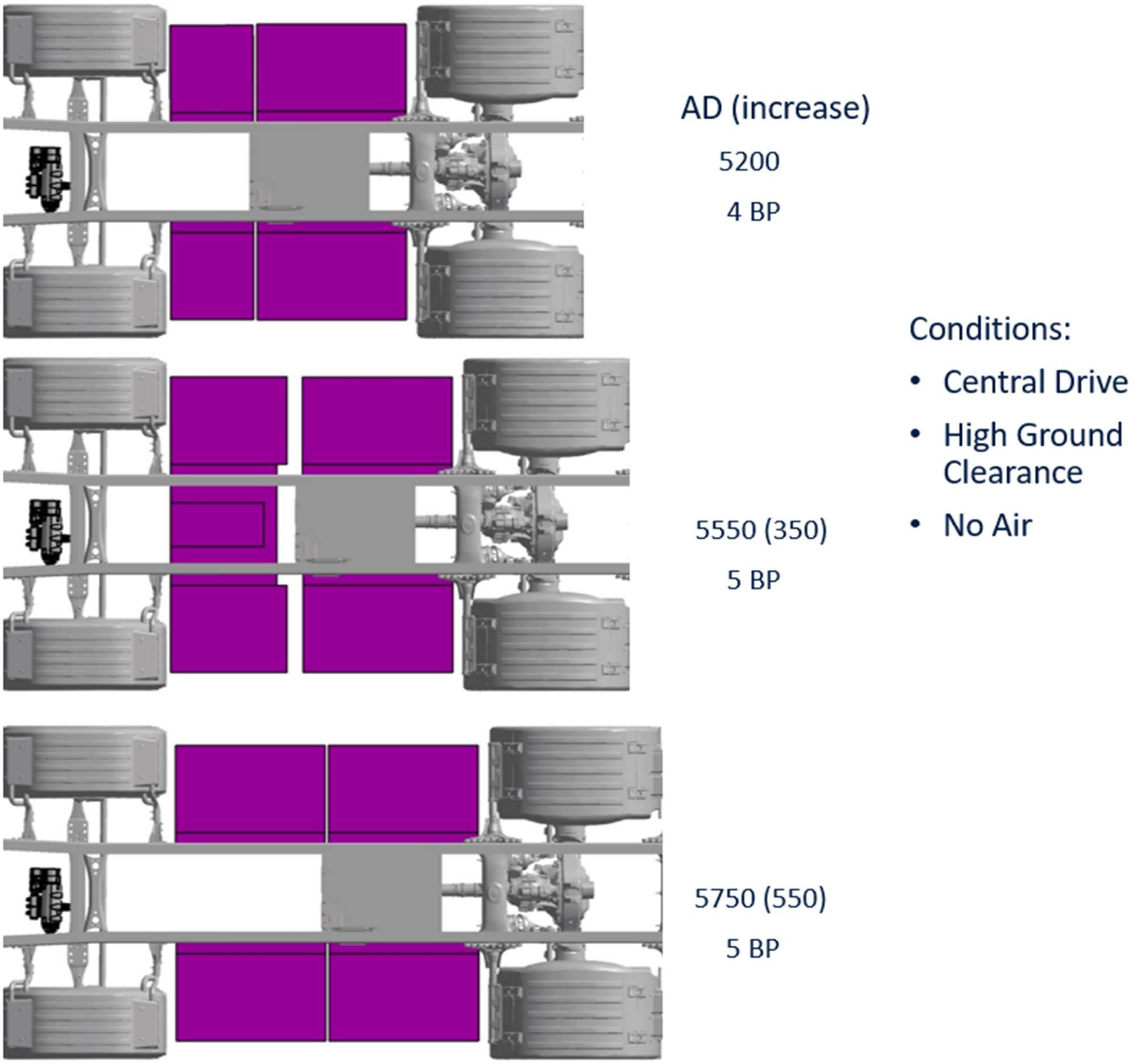


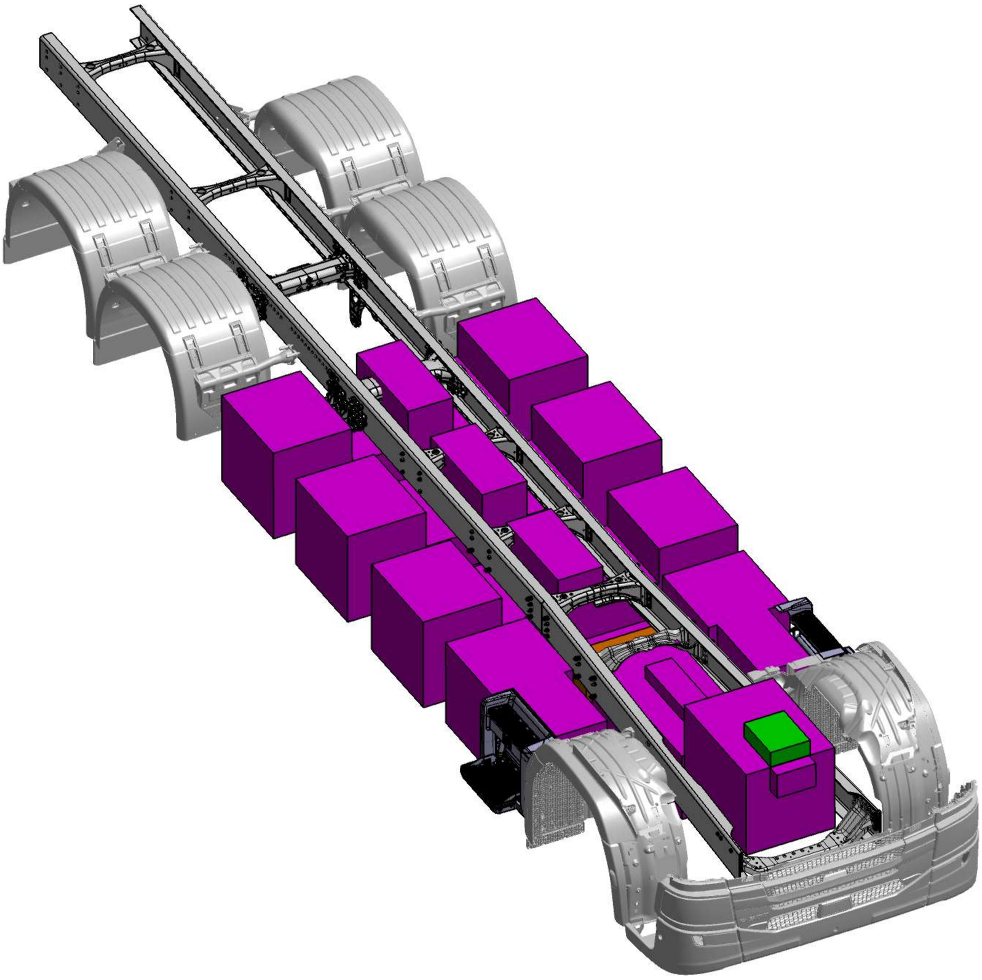
Figure 4.18: Impact of Complex Shaped Batteries

From the picture, in order to increase the energy storage after 5200AD, by using complex shaped batteries, AD needs to be increased only by 350 mm whereas box shaped batteries require an increase of 550 mm. Therefore, it can be derived that using complex shaped batteries helps reduce the AD increase for the same energy storage demand. This phenomenon was found only for few of the 96 scenarios and not all, therefore the benefits of complex shaped batteries needs to be further investigated.

To give an example of a scenario where complex shaped batteries didn't add any advantage, while analyzing the layout for the maximum axle for 6x2, it was found that using complex or box shaped battery pack resulted in the same amount of maximum battery packs in each scenario. Due to this, there are no clear benefits of using either of the battery pack types over the other to increase the energy storage on 6x4 layout. Which is why this needs to be further investigated.

4.7.2.2. Frame

The design and placement of the batteries is affected by the design of the frame. There is a risk that cross members might collide with complex shaped batteries and might therefore need to be moved. Therefore, it is in the best of interest to investigate this when designing electric trucks. As it can be seen in *Figure 4.19*, the box of the batteries clashes sometimes with the existing crossmembers.



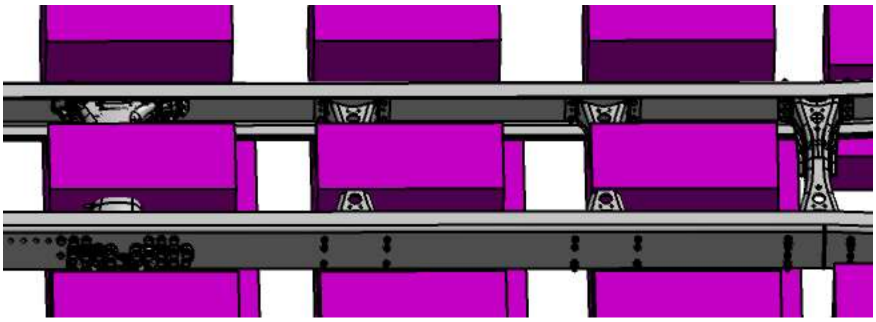


Figure 4.19 – Crossmember Clash with Batteries

4.7.2.3. Results

The number of battery packs that could be fitted onto each vehicle layout for high and low ground clearance for axle distance increase were compiled into the *Table 4.2* below. The boxes highlighted in yellow, represent the use of complex batteries are described in the chapter above and the grey boxes denote that there is no possibility to increase the energy storage for that axle distance on that particular layout.

	6x2		6x2/4		8x4	
AD [mm]	High GC	Low GC	High GC	Low GC	High GC	Low GC
2950	2 BP	3 BP				
3400	4 BP	4 BP				
3750		6 BP				
4050	5 BP		2 BP	3 BP		
4150					2 BP	2 BP
4300						3 BP
4350			3 BP	4 BP		
4400		7 BP				
4550					3 BP	
4650			4 BP			
4700	6 BP	8 BP		5 BP		
4950						4 BP
5000				6 BP		
5200	7 BP				4 BP	5 BP
5300		9 BP	5 BP			
5550					5 BP	
5750					5 BP	
5850	8 BP					
5900						6 BP
6100						7 BP
6300					6 BP	
6350	9 BP	11 BP				
6400					6 BP	
6550					7 BP	8 BP

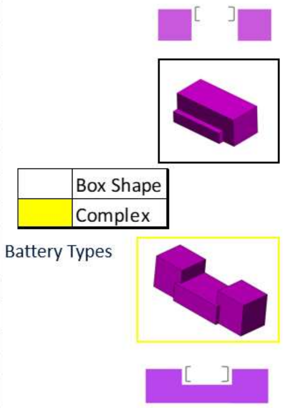


Table 4.2: Results of Axle Distance Increase

From the picture 6x2 provides a higher chance of having more energy storage on the truck compared to 6x2/4 and 8x4. Additionally, it can be seen that axle distance increase needs to be done in certain amount in order to increase the axle distance and in some cases complex shaped batteries provide the opportunity to increase the energy storage for shorter axle distances.

5. Conclusion

5.1. Project

The project was done from the perspective of modular toolbox and layout; therefore, the conclusions are derived from toolbox and layout analysis. From the toolbox analysis, the ideal position for most of the components required for an electric truck were determined. It was found that components of power electronics need to be kept close to each other in an accessible and standardized position in order to reduce the cabling and to provide easy access to those that requires regular attention. The standard position suggested through this project for power electronics is around the battery that is placed in the engine tunnel.

Electric Power Steering (EPS) is an energy efficient choice that need to be adapted for electric vehicles but needs redesign since the models available right now are bigger and clash with other components surrounding it. This issue can also be solved through IVD (Increased Vehicle Dimensions), from the Directive (EU) 2015/719 of the European parliament and of the council amending Council Directive 96/53/EC laying down for certain road vehicles to have increased dimensions.

It is beneficial to route the media along the inside of the frame in order to reduce the complexity of the media going across the truck. This poses certain complications as discussed earlier, for example in the areas where the media is dense, assembly and disassembly of components attached to the frame in those locations will be difficult. Therefore, this needs to be analyzed further.

Multiple conclusions can be drawn for batteries. One of which is the placement of a standardized battery in the engine tunnel. When it comes to the form factors, it was observed that split batteries help fill the small free space pockets available in different layouts. Complex shaped batteries can help place batteries for shorter axle distances for some cases which is why it should be analyzed further. Through the analysis conducted during the project, it was evident that the assumptions taken regarding battery sizes and assembly are not ideal since there was lot of free space available on the truck which couldn't be filled with these batteries, therefore the battery sizes and assumptions need to be readapted and redesigned. While redesigning the batteries, it is beneficial to keep in mind that batteries can be integrated with boarding steps, thus increasing the energy storage on the truck as discussed in previous chapters.

From the battery layout analysis, it was evident that E-Axle has clear benefits over Central Drive in terms of energy storage since E-Axle occupies less space on the layout, therefore it should be strived to use E-Axles in future electric vehicles. Also, it was seen that mechanical suspension need to be redesigned since it is preventing the placement of batteries especially the spring bolts that protrude as seen in previous chapter.

From toolbox analysis it was evident that removing compressed air from the system provides the electric truck with multiple benefits. It increases the energy efficiency of the truck thus increasing the range and reducing the operating costs of the truck. It also helps in saving some space on the truck that can be used to store any other desired components.

Finally, it was also seen that frame has been optimized for the presence of engine which is why it has a bent shape in the front that is preventing the placement of batteries which is why it needs to be readapted and optimized for electric trucks. Also, the crossmembers of the frame need to be adapted since they are clashing with batteries in few cases and due to the fact, the batteries add lot of weight on the truck which requires the crossmembers to be either redesigned or increased in number.

5.2. Personal

On a personal level, by doing this project we have acquired a great amount of knowledge regarding ICE powered trucks, modularity, need for electrification and electric trucks. This experience has been informative and educational in the way that we were able to learn and adapt from the mistakes that were made along the way. The project taught us the importance of setting boundaries since the scope of the project was too large. Electrification being a relatively new subject to us, gave us the opportunity to explore its every nook and corner which consumed lot of time and effort and forced us to create some boundaries in order to restrict ourselves to the subject at hand so that the objectives of the project can be fulfilled. This was done by maintaining a holistic approach while analyzing alternative electric solutions for different components of the truck. Doing a detailed analysis of these alternatives was an exciting prospect but we had to limit ourselves to a holistic approach in order to finish the project in time.

Setting boundaries proved to be extremely important while doing battery layout analysis when the initial plan of doing layout for three vehicle configurations grew to be 96 scenarios. A swift action was needed in terms of setting the boundaries in order to limit the number of scenarios from growing out of hand.

Another important learning, we had during the course of the project was division of time. At the start of the project, the scope of the project was divided into three main segments, pre study, toolbox analysis and layout analysis and the available time was divided equally between these. This approach worked well for the first two segments but while doing the last one which is the layout analysis, as mentioned earlier, the scenarios grew to be 96 and the time assigned proved to be insufficient. Therefore, for the last 4 weeks of the project, we had to work 12 hours a day without any breaks on weekends. If we were to convey a message to our past selves at the start of the project, we would implore them to reconsider the division of time in order to assign more time towards the layout analysis.

Additionally, from the initial interviews that were conducted we learned to be precise with the questions asked to ensure that the information that was needed can be acquired without collecting an overflow of information through open questions that is not relevant to the project. This learning we were able to apply to the interviews that were conducted in the later stages of the project.

6. Recommendations

6.1. Infrastructure for Future Electric Vehicles

Before electric trucks can be utilized to a high degree in our societies it must also be ensured that there is an infrastructure available which can provide the necessary electrical energy to the trucks. Therefore, it is necessary to not only focus on how the vehicles can be built, but also how they can be used and charged. If this aspect is not considered, then there is a risk that the implementation of electrified vehicles will not be as successful. It is therefore advisable to conduct an analysis regarding how the future infrastructure may look so that more insights can be gained regarding how future trucks should be designed.

6.2. Alternate Energy Storage Solutions

It should also be analyzed whether there are other more suitable energy storage solutions than lithium ion batteries. Fuel Cells and structural batteries were presented in the pre-study of this thesis and had some interesting characteristics. It is also worth considering what will happen if the entire automotive industry transitions towards using lithium ion batteries in their vehicles. Will the resources then be enough to supply this need in the long term? And is it possible to recycle old lithium ion batteries so that they can be reused? These are some important questions which must be considered to ensure that the solutions of the future truly are sustainable.

It was also found during the battery layout analysis that part of the difficulty of placing the propulsion batteries was due to the form factors of the batteries. The form factors were heavily influenced and limited by the shape, dimension and assumptions regarding the modules within the battery packs. However, should an alternative module design be used then there is a possibility that even more form factors can be achieved, meaning that Scania will be able to offer even more performance steps with regards to the shapes of the battery packs. This can in turn help to increase the ability to tailor the layout of the truck which can thereby help to better utilize free space on the layout and store more batteries. Therefore, it is also beneficial to further analyze alternative modules designs.

6.3. Compressed Air Affected Systems

As mentioned earlier, if the compressed air is removed then many systems around the truck will be affected. Some of these systems includes the chairs in the cab, the suspension to the cab as well as brakes and suspension on the trailers. Therefore, if the compressed air circuit is removed, it is also essential to propose alternative solutions for these areas as well to ensure that the truck can be fully utilized by the customer. These areas should therefore be further analyzed to make it possible to fully eliminate compressed air from the trucks.

6.4. Ergonomic Charging Interface

Since the charging interface will be used often by the user and the cables to the external energy source may be thick and heavy an ergonomic study should thus be performed on the charging interface. This analysis should include both design and position of the interface as well as how a charging station may be designed. This will help to ensure that the customers and users are satisfied with the product and that they do not feel discomfort after using the product after a long period of time.

6.5. Steer by Wire

As previously mentioned, steer by wire removes the mechanical linkage between the driver and the steered wheels. This in turn would help to give left- and right-hand drive trucks similar production properties since the layout excluding the cab would be very similar. Steer by wire can also help to increase the maximum steering angle which can help vehicles to maneuver in space limited environments. Additionally, since autonomous vehicles is a growing trend and will not require any steering wheel if they are fully autonomous, they will most likely operate using steer by wire. Therefore, it is beneficial to analyze this technology to see how this solution can be designed so that it can be used on both manually driven as well as autonomous vehicles and provide benefits to both.

6.6. China and Electric Vehicle Implementation

China has already implemented electric vehicles to a large degree. Therefore, it may be beneficial to study the design of their vehicles and how they are handling the infrastructure and legal aspects to support this. It is for example known that their electric trucks are using high voltage power steering. Therefore, the benefits should be further investigated to see whether Scania should do this as well. Similarly, the legal aspects regarding electrified components such as EMB and Steer by Wire can be investigated to see if similar regulations can be implemented within other markets.

6.7. Mass Analysis

Since batteries are heavy and are mounted along the truck it means that the total weight of the truck may increase when comparing to conventional ICE trucks. Not only that, but the weight distribution to the rear axles may increase which may negatively impact the customers payload. Since customers make much of their money due to the payload capacity of the truck this is thereby an important factor to consider when design electric trucks to ensure that they are still an attractive option to customers. It should also be analyzed how the IVD legislation will impact this.

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8. Appendices

8.1. Results Layout Analysis

8.1.1. 6x2

8.1.1.1.1. CD Low GC

<u>None:</u>
This layout could fit 3 battery packs.

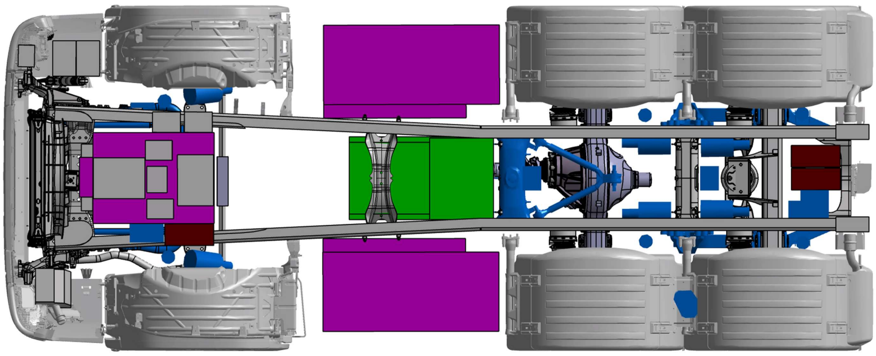


Figure 8.1 – 6x2 CD Low GC None Top View

<u>Compressed Air:</u>
This layout could fit 3 battery packs.

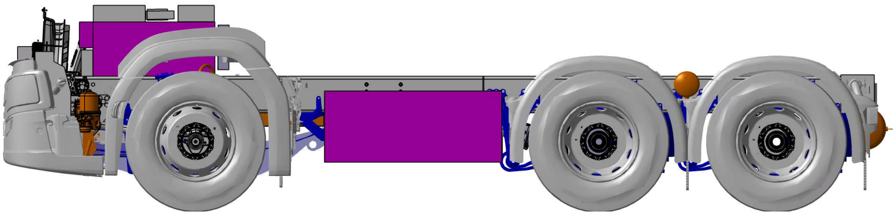


Figure 8.2 –6x2 CD Low GC Compressed Air Side View

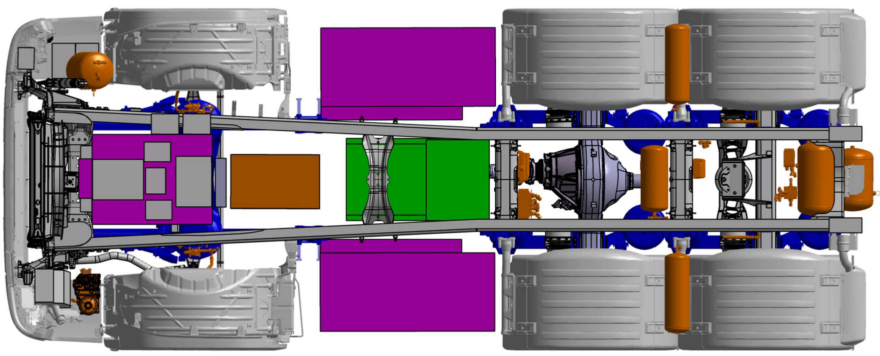


Figure 8.3 –6x2 CD Low GC Compressed Air Top View

<u>Hydraulic PTO:</u>
This layout could fit 2 battery packs.

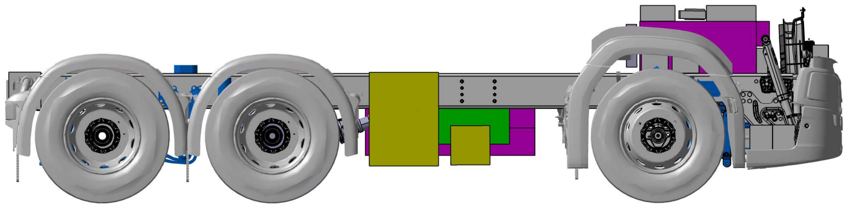


Figure 8.4 –6x2 CD Low GC Hydraulic PTO Side View

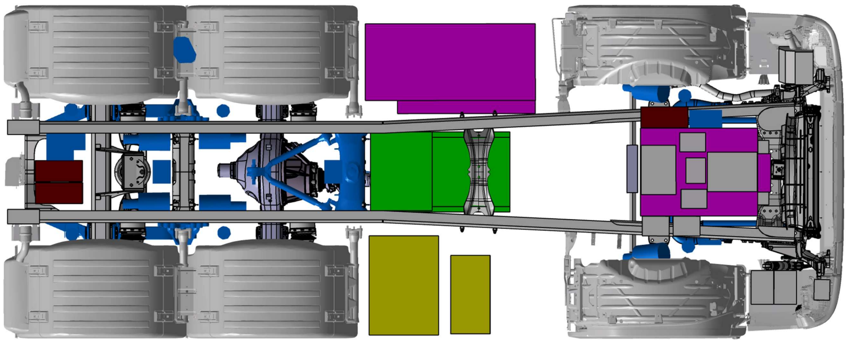


Figure 8.5 –6x2 CD Low GC Hydraulic PTO Top View

<u>Both:</u>
This layout could fit 2 battery packs.

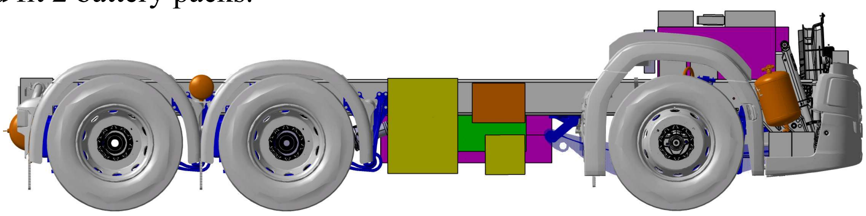


Figure 8.6 – 6x2 CD Low GC Both Side View

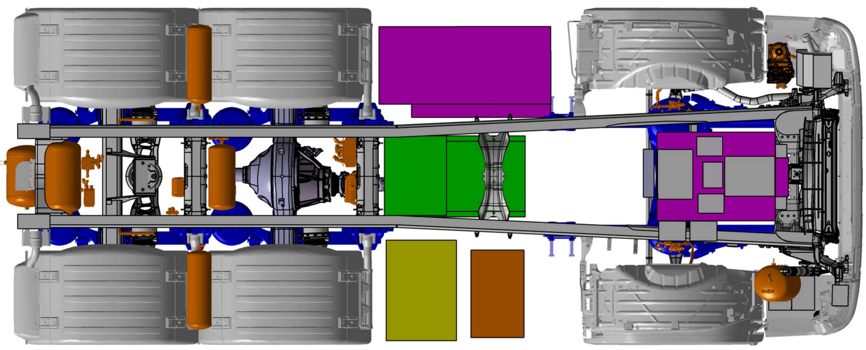


Figure 8.7 – 6x2 CD Low GC Both Top View

8.1.1.1.2. CD High GC

<u>None:</u>
This layout could fit 3 battery packs.

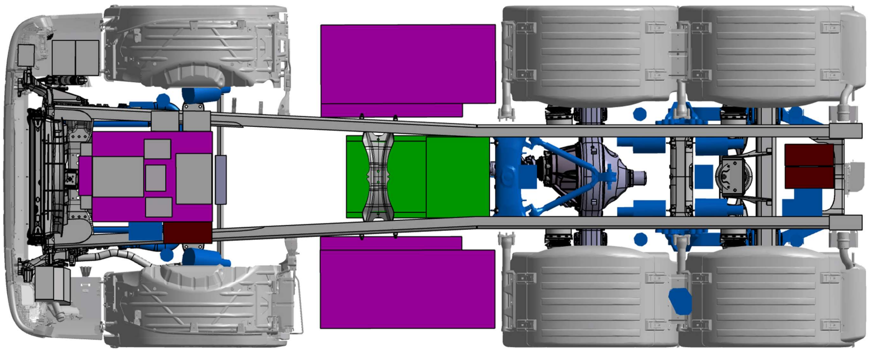


Figure 8.8 – 6x2 CD High GC None Top View

Compressed Air:
This layout could fit 3 battery packs.

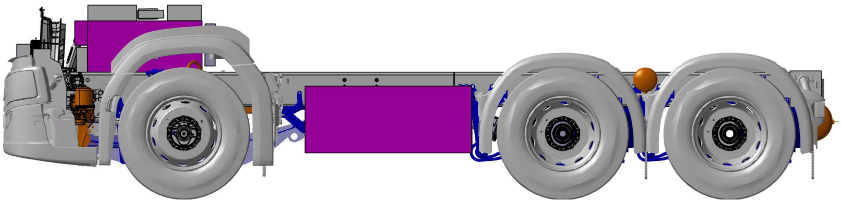


Figure 8.9 – 6x2 CD High GC Compressed Air Side View

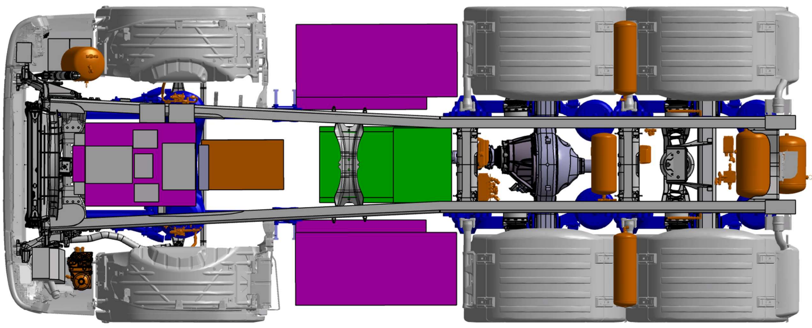


Figure 8.10 – 6x2 CD High GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 2 battery packs.

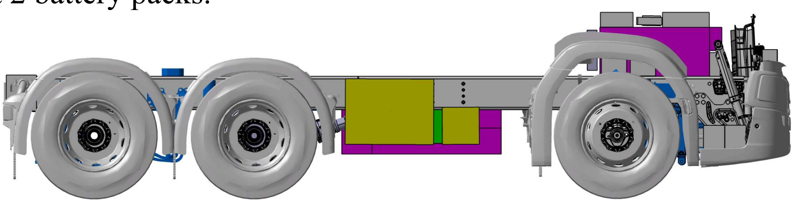


Figure 8.11 – 6x2 CD High GC Hydraulic PTO Side View

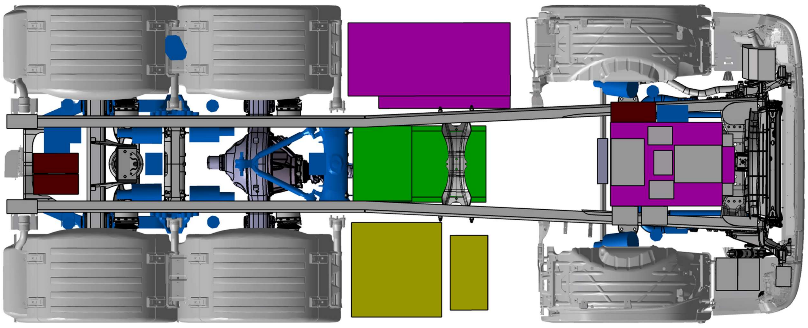


Figure 8.12 – 6x2 CD High GC Hydraulic PTO Top View

Both:
This layout could fit 2 battery packs.

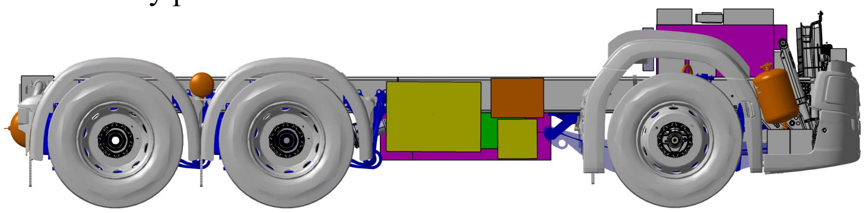


Figure 8.13 – 6x2 CD High GC Both Side View

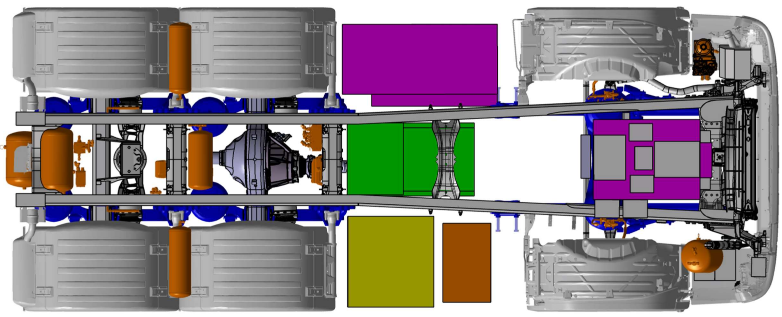


Figure 8.14 – 6x2 CD High GC Both Top View

8.1.1.1.3. E-Axle Low GC

None:
This layout could fit 4 battery packs.

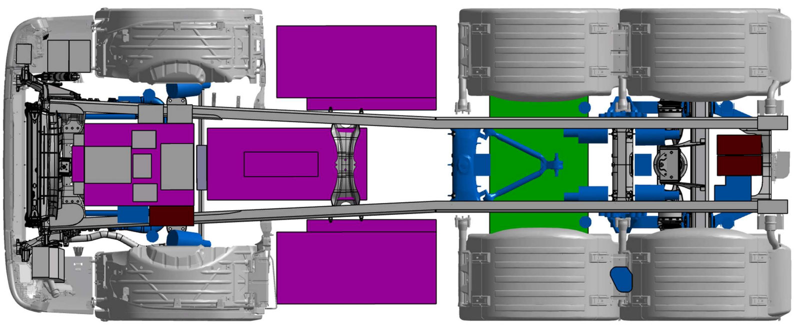


Figure 8.15 – 6x2 E-Axle Low GC None Top View

Compressed Air:
This layout could fit 4 battery packs.

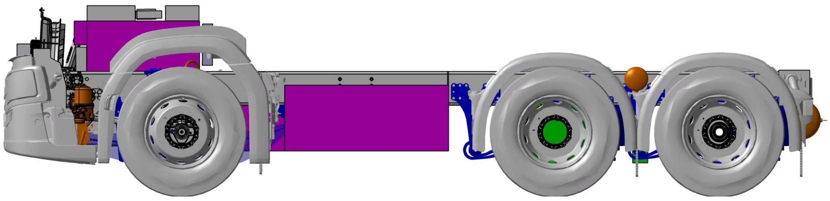


Figure 8.16 – 6x2 E-Axle Low GC Compressed Air Side View

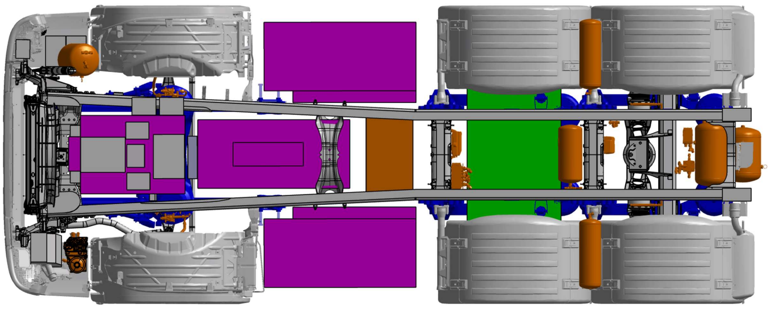


Figure 8.17 – 6x2 E-Axle Low GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 3 battery packs.

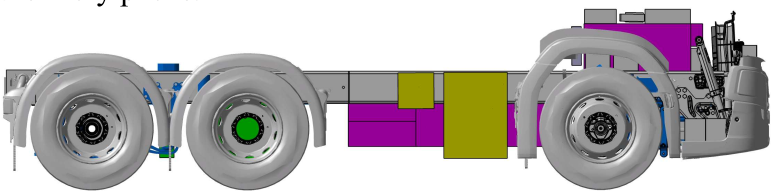


Figure 8.18 – 6x2 E-Axle Low GC Hydraulic PTO Side View

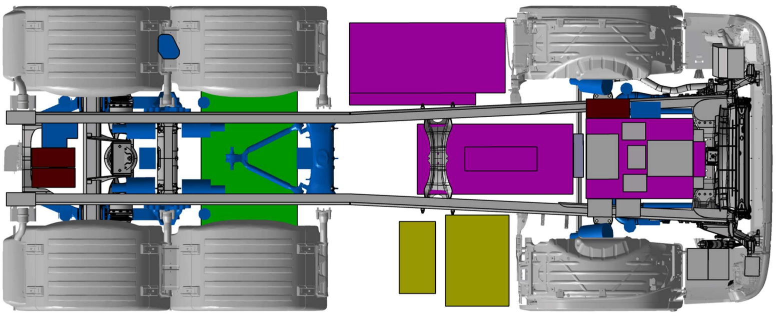


Figure 8.19 – 6x2 E-Axle Low GC Hydraulic PTO Top View

Both:

This layout could fit 3 battery packs.

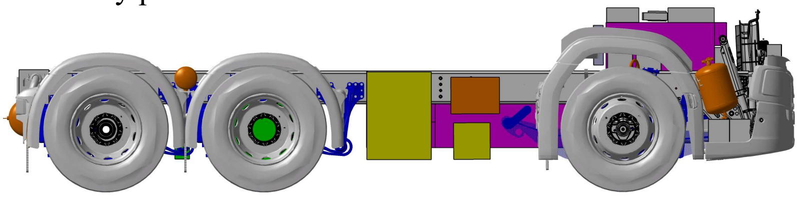


Figure 8.20 – 6x2 E-Axle Low GC Both Side View

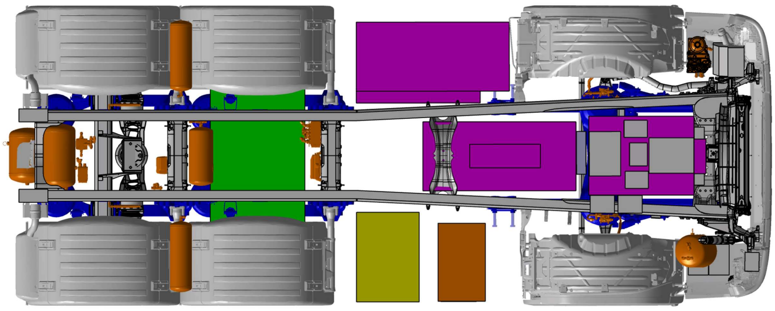


Figure 8.21 – 6x2 E-Axle Low GC Both Top View

8.1.1.1.4. E-Axle High GC

None:

This layout could fit 4 battery packs.

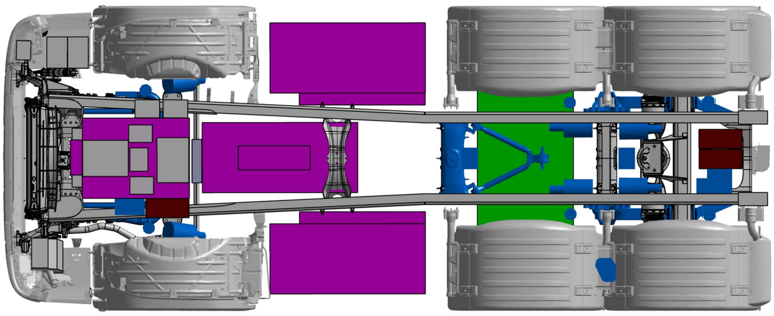


Figure 8.22 – 6x2 E-Axle High GC None Top View

Compressed Air:

This layout could fit 4 battery packs.

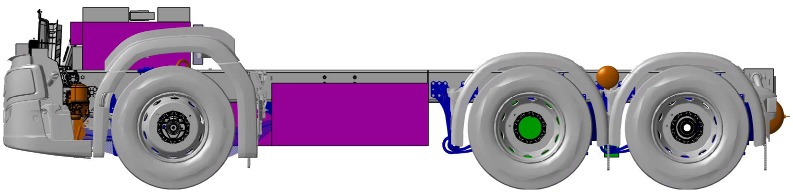


Figure 8.23 – 6x2 E-Axle High GC Compressed Air

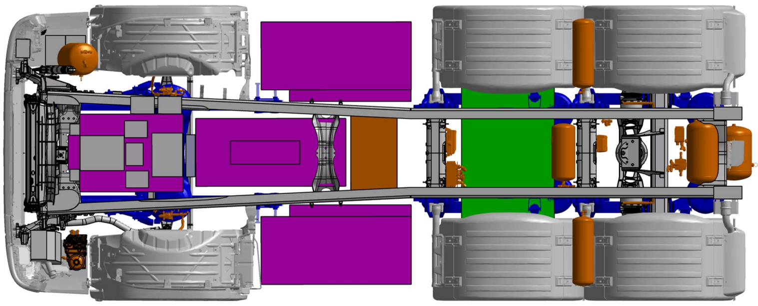


Figure 8.24 – 6x2 E-Axle High GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 3 battery packs.

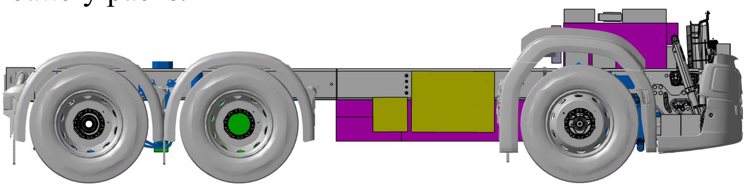


Figure 8.25 – 6x2 E-Axle High GC Hydraulic PTO Side View

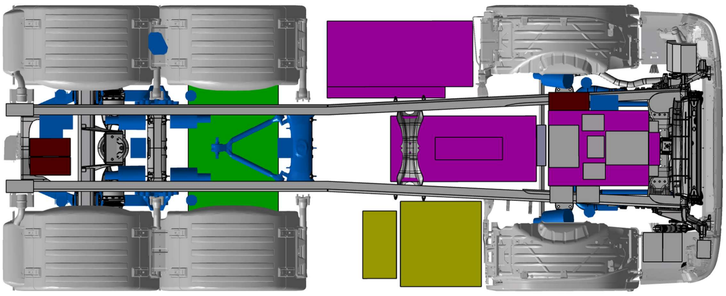


Figure 8.26 – 6x2 E-Axle High GC Hydraulic PTO Top View

Both:
This layout could fit 3 battery packs.

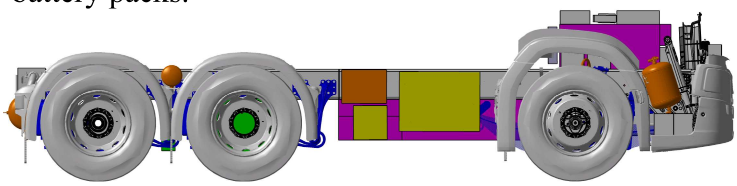


Figure 8.27 – 6x2 E-Axle High GC Both Side View

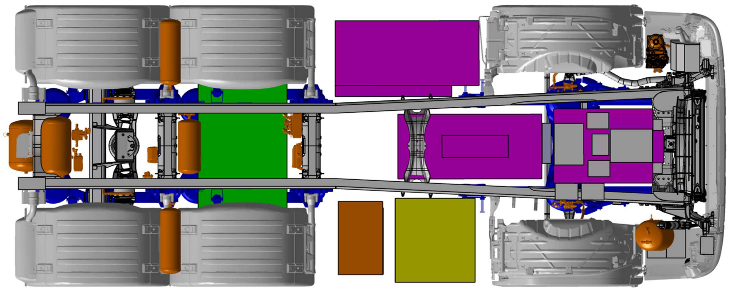


Figure 8.28 – 6x2 E-Axle High GC Both Top View

8.1.1.2. Boarding Step Scenarios

8.1.1.2.1. E-Axle Low GC:

<u>None:</u>
This layout could fit 4 battery packs.

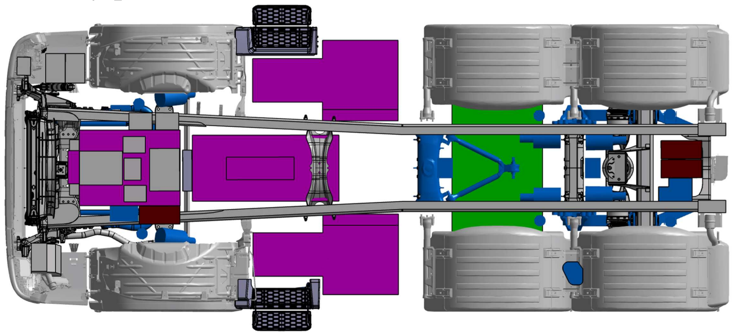


Figure 8.29 – Boarding Steps 6x2 E-Axle Low GC None top View

<u>Compressed Air:</u>
This layout could fit 4 battery packs.

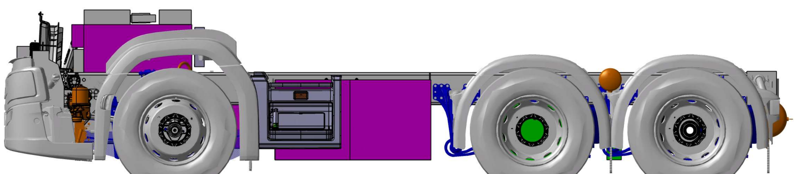


Figure 8.30 – Boarding Steps 6x2 E-Axle Low GC Compressed Air Side View

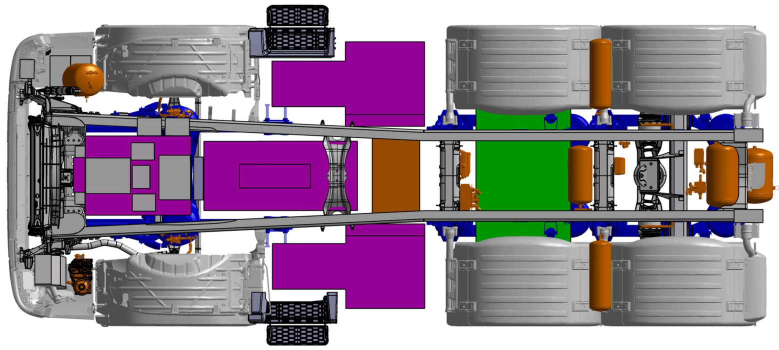


Figure 8.31 – Boarding Steps 6x2 E-Axle Low GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 3 battery packs.

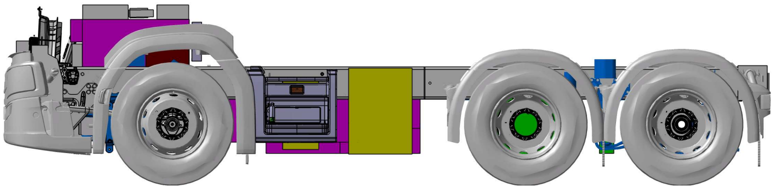


Figure 8.32 – Boarding Steps 6x2 E-Axle Low GC Hydraulic PTO Side View

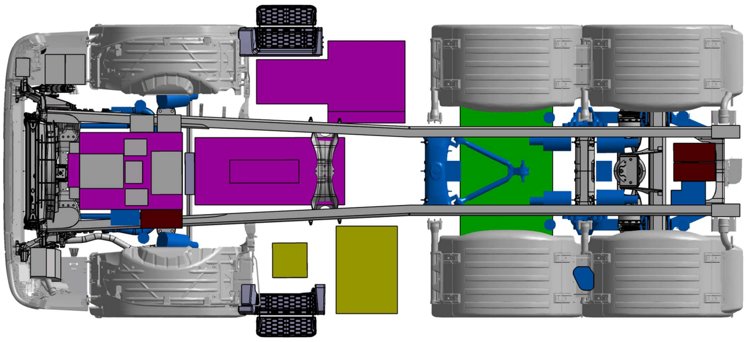


Figure 8.33 – Boarding Steps 6x2 E-Axle Low GC Hydraulic PTO Top View

Both:
This layout could fit 3 battery packs.

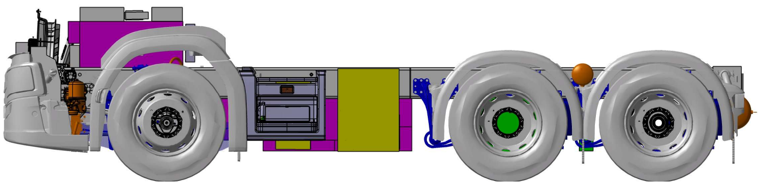


Figure 8.34 – Boarding Steps 6x2 E-Axle Low GC Both Side View

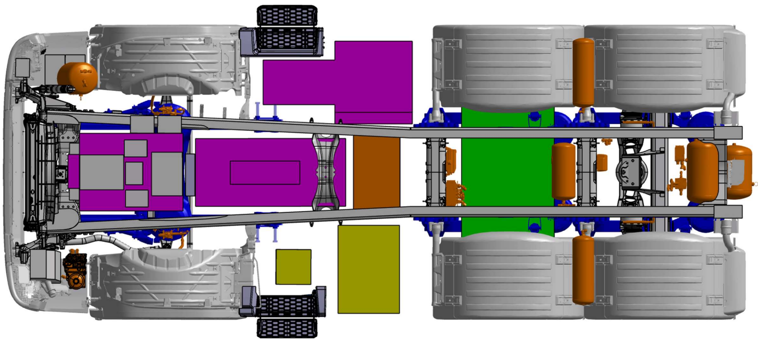


Figure 8.35 – Boarding Steps 6x2 E-Axle Low GC Both Top View

8.1.1.2.2. E-Axle High GC:

<u>None:</u>
This layout could fit 3 battery packs.

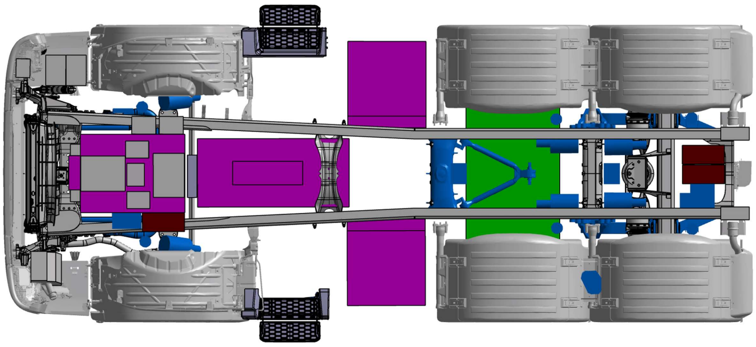


Figure 8.36 – Boarding Steps 6x2 E-Axle High GC None Top View

<u>Compressed Air:</u>
This layout could fit 3 battery packs.

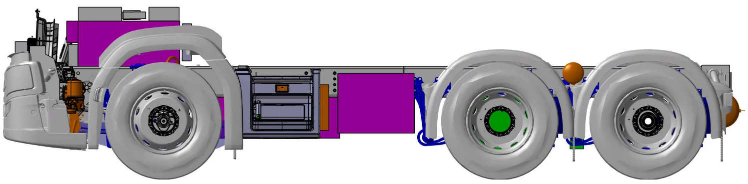


Figure 8.37 – Boarding Steps 6x2 E-Axle High GC Compressed Air Side View

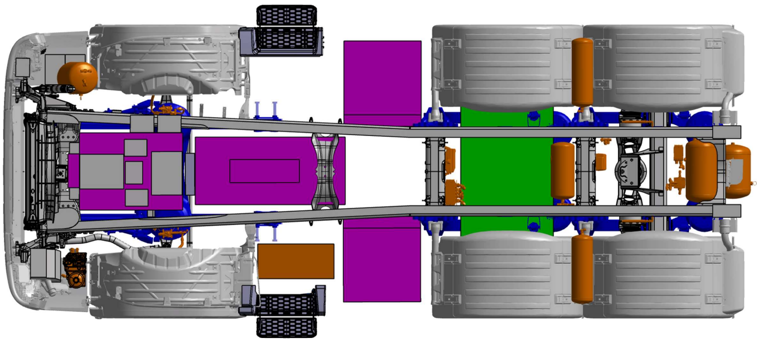


Figure 8.38 – Boarding Steps 6x2 E-Axle High GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 2 battery packs.

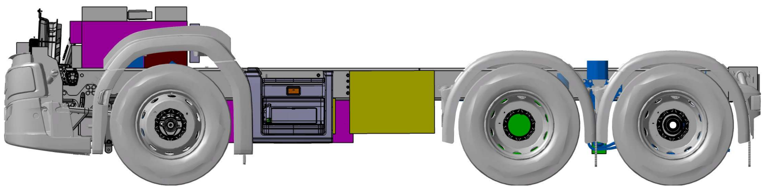


Figure 8.39 – Boarding Steps 6x2 E-Axle High GC Hydraulic PTO Side View

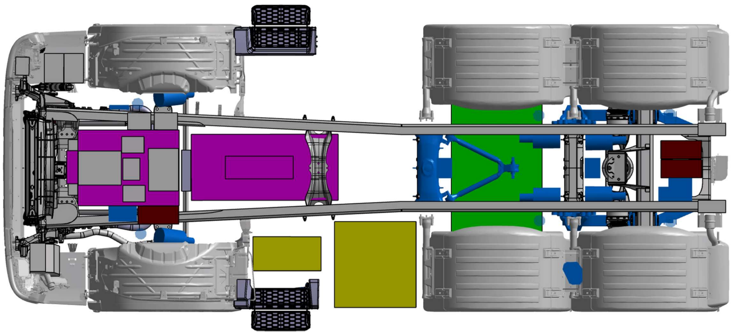


Figure 8.40 – Boarding Steps 6x2 E-Axle High GC Hydraulic PTO Top View

Both:
This layout could fit 2 battery packs.

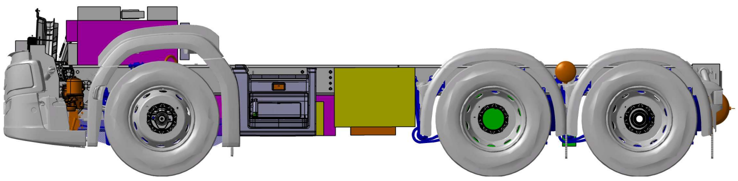


Figure 8.41 – Boarding Steps 6x2 E-Axle High GC Both Side View

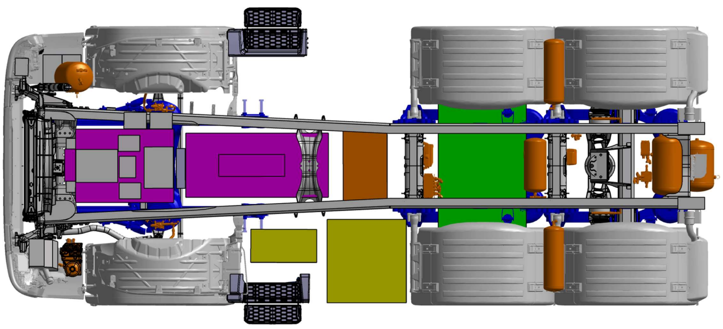


Figure 8.42 – Boarding Steps 6x2 E-Axle High GC Both Top View

8.1.1.2.3. CD Low GC

<u>None:</u>
This layout could fit 3 battery packs.

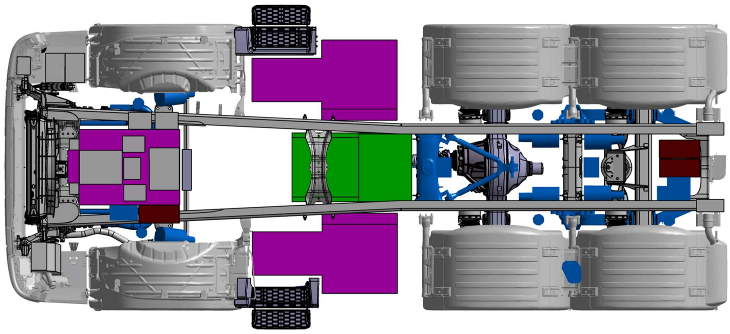


Figure 8.43 – Boarding Steps 6x2 CD Low GC None Top View

<u>Compressed Air:</u>
This layout could fit 3 battery packs.

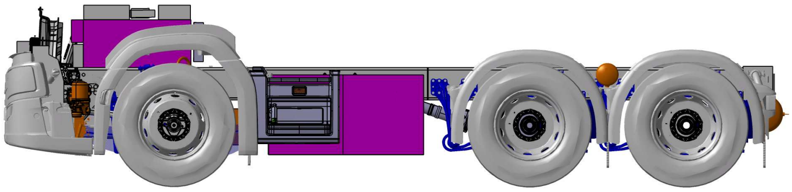


Figure 8.44 – Boarding Steps 6x2 CD Low GC Compressed Air Side View

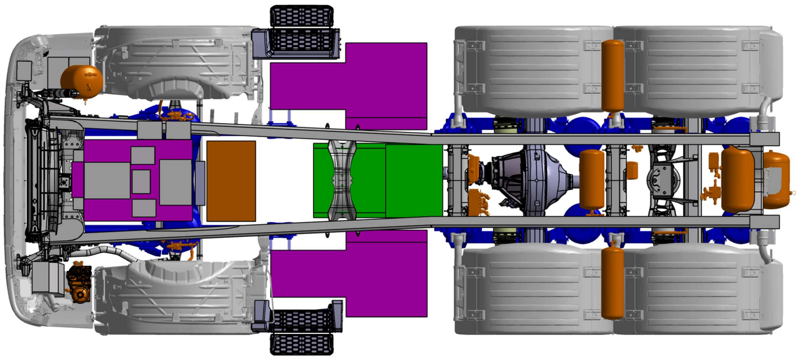


Figure 8.45 – Boarding Steps 6x2 CD Low GC Compressed Air Top View

<u>Hydraulic PTO:</u>
This layout could fit 2 battery packs.

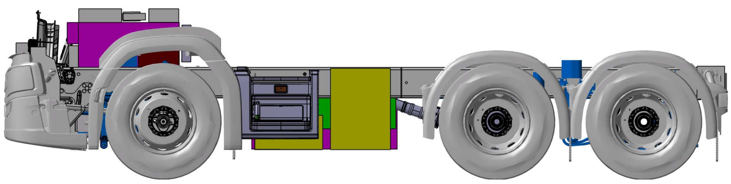


Figure 8.46 – Boarding Steps 6x2 CD Low GC Hydraulic PTO Side View

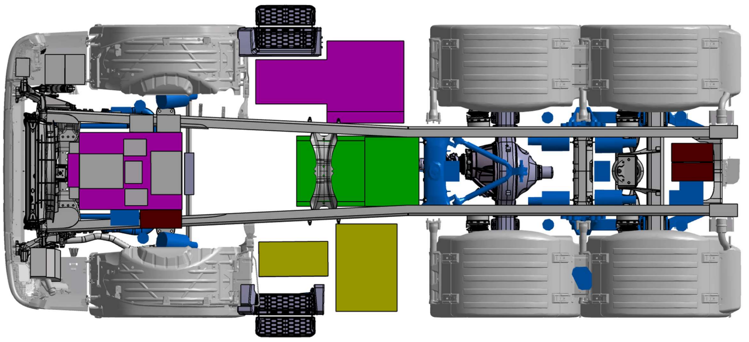


Figure 8.47 – Boarding Steps 6x2 CD Low GC Hydraulic PTO Top View

Both:
This layout could fit 2 battery packs.

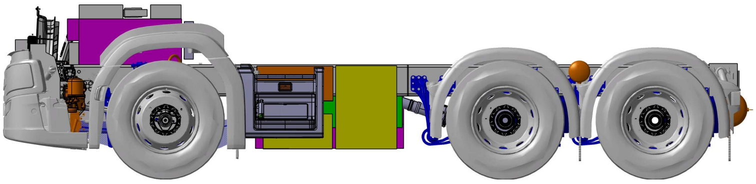


Figure 8.48 – Boarding Steps 6x2 CD Low GC Both Side View

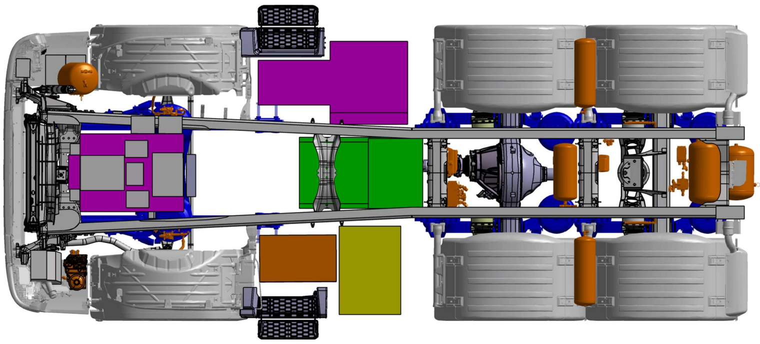


Figure 8.49 – Boarding Steps 6x2 CD Low GC Both Top View

8.1.1.2.4. CD High GC

None:
This layout could fit 2 battery packs.

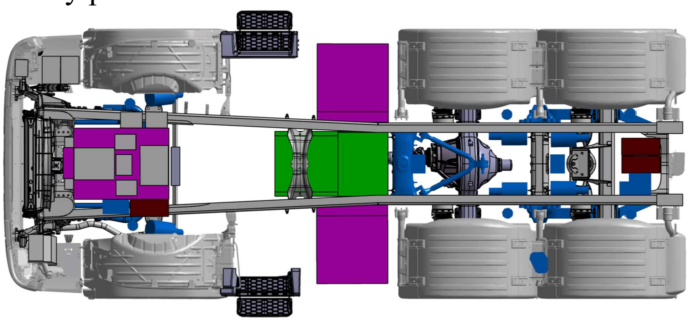


Figure 8.50 – Boarding Steps 6x2 CD High GC None Top View

Compressed Air:
This layout could fit 2 battery packs.

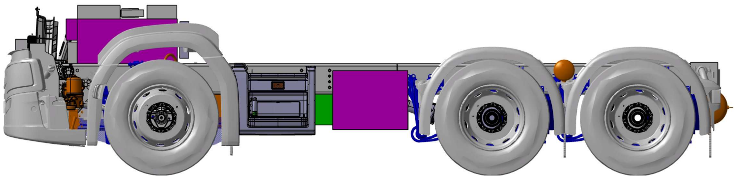


Figure 8.51 – Boarding Steps 6x2 CD High GC Compressed Air Side View

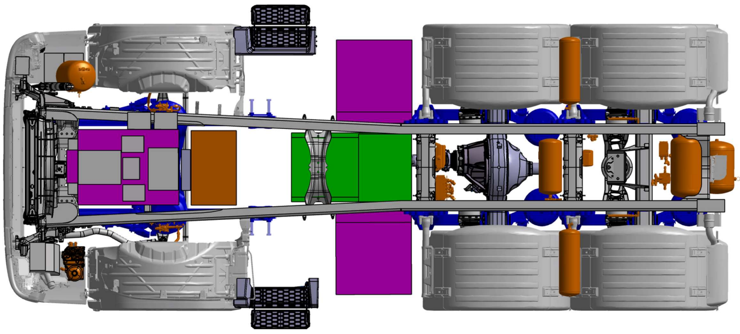


Figure 8.52 – Boarding Steps 6x2 CD High GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 2 battery packs.

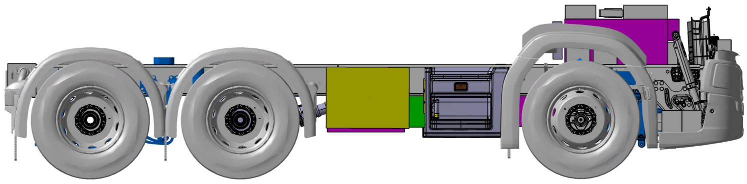


Figure 8.53 – Boarding Steps 6x2 CD High GC Hydraulic PTO Side View

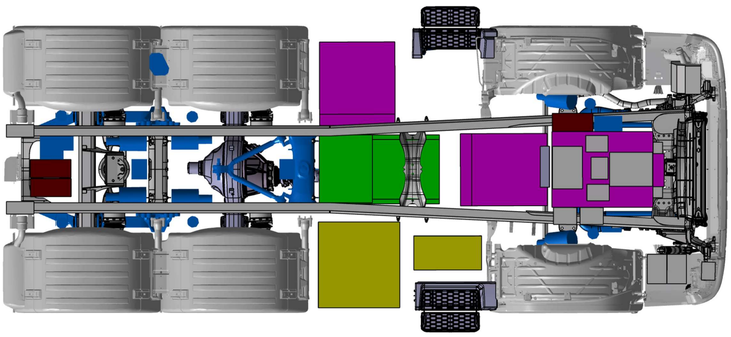


Figure 8.54 – Boarding Steps 6x2 CD High GC Hydraulic PTO Top View

Both:
This layout could fit 2 battery packs.

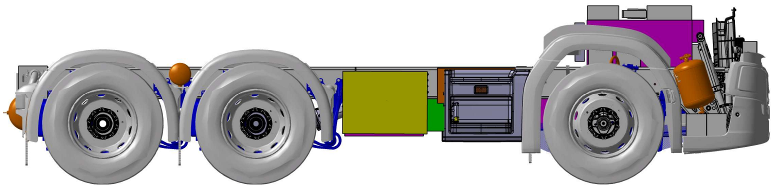


Figure 8.55 – Boarding Steps 6x2 CD High GC Both Side View

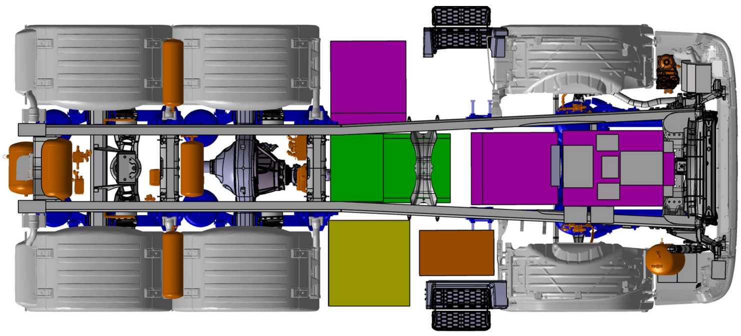


Figure 8.56 – Boarding Steps 6x2 CD High GC Both Top View

8.1.1.3. Increased Axle distance

8.1.1.3.1. Low GC:

0 mm Increase:
This layout can fit 3 battery packs.

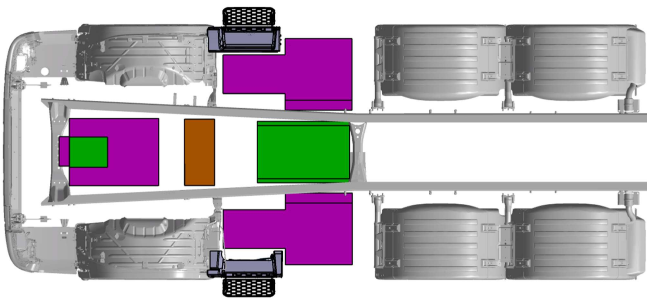


Figure 8.57 – 0 mm Axle Distance Increase 6x2 Low GC Top View

450 mm Increase:
This layout could fit 4 battery packs.

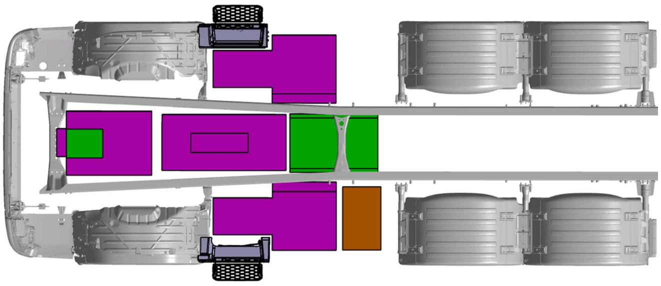


Figure 8.58 – 450 mm Axle Distance Increase 6x2 Low GC Top View

800 mm Increase:
This layout could fit 6 battery packs.

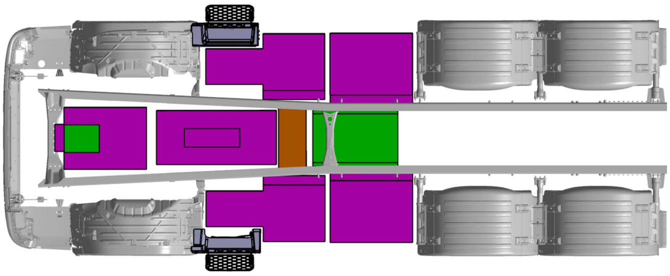


Figure 8.59 – 800 mm Axle Distance Increase 6x2 Low GC Top View

1450 mm Increase:
This layout could fit 7 battery packs.

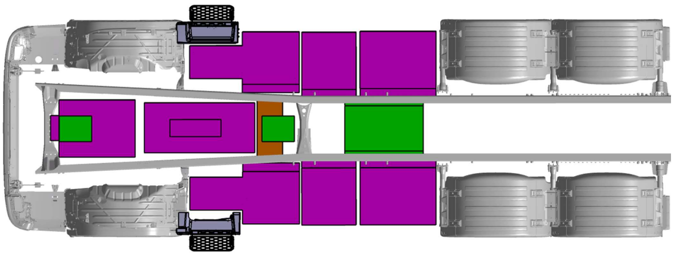


Figure 8.60 – 1450 mm Axle Distance Increase 6x2 Low GC Top View

1700 mm Increase:
This layout could fit 8 battery packs.

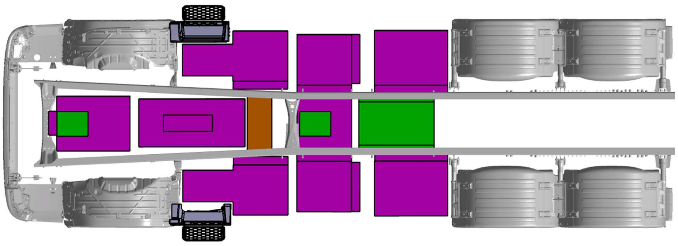


Figure 8.61 – 1700 mm Axle Distance Increase 6x2 Low GC Top View

2350 mm Increase:
This layout could fit 9 battery packs.

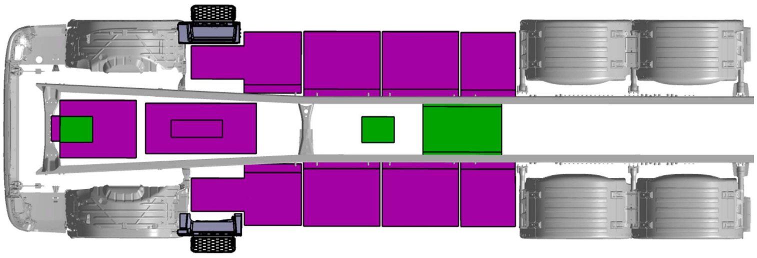


Figure 8.62 – 2350 mm Axle Distance Increase 6x2 Low GC Top View

2600 mm Increase:
This layout could fit 10 battery packs.

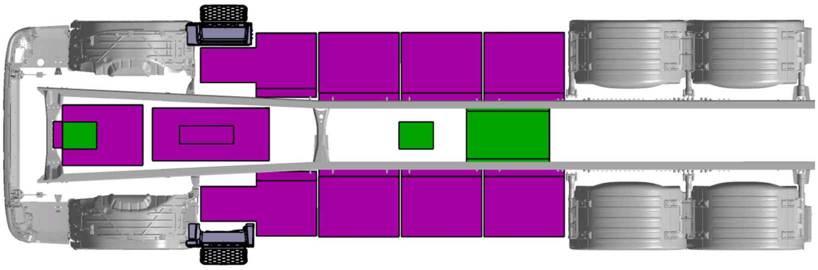


Figure 8.63 – 2600 mm Axle Distance Increase 6x2 Low GC Top View

3300 mm Increase:
Scenario 1:
This layout could fit 11 battery packs.

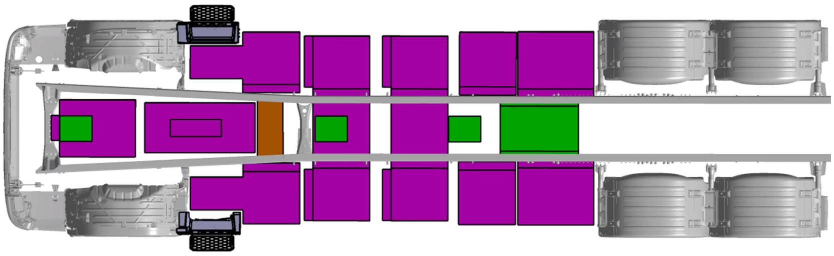


Figure 8.64 – 3300 mm Axle Distance Increase 6x2 Low GC Scenario 1 Top View

Scenario 2:
This layout could fit 11 battery packs.

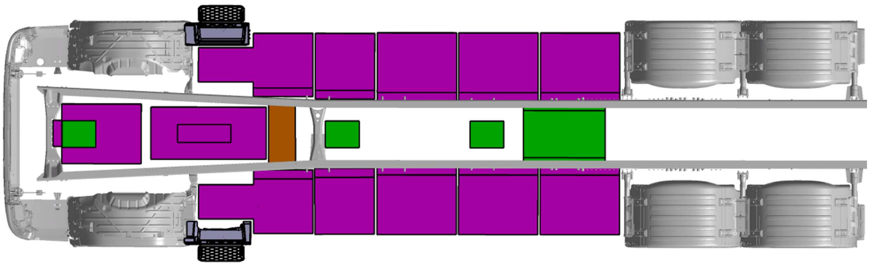


Figure 8.65 – 3300 mm Axle Distance Increase 6x2 Low GC Scenario 2 Top View

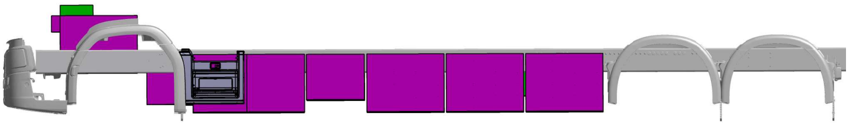


Figure 8.66 – 3300 mm Axle Distance Increase 6x2 Low GC Scenario 2 Side View

8.1.1.3.2. High GC:

0 mm Increase:

This layout could fit 2 battery packs.

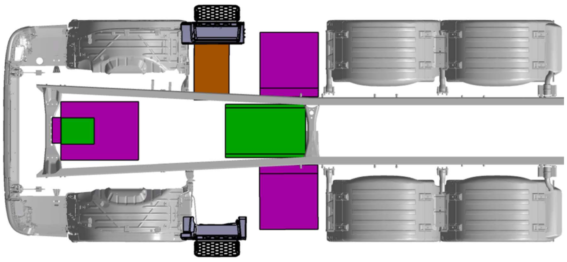


Figure 8.67 – 0 mm Axle Distance Increase 6x2 High *GC Top View*

450 mm Increase:

This layout could fit 4 battery packs.

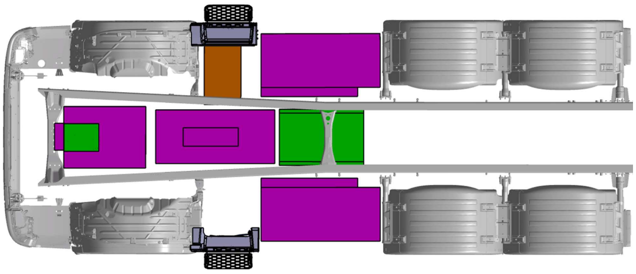


Figure 8.68 – 450 mm Axle Distance Increase 6x2 High *GC Top View*

1100 mm Increase:

This layout could fit 5 battery packs.

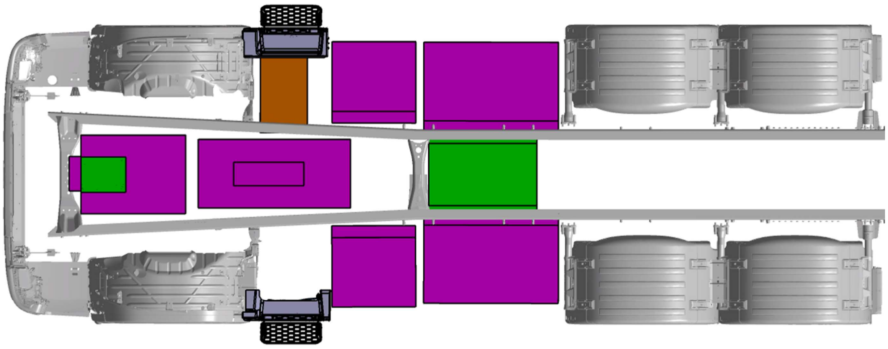


Figure 8.69 – 1100 mm Axle Distance Increase 6x2 High *GC Top View*

1750 mm Increase:
This layout could fit 6 battery packs.

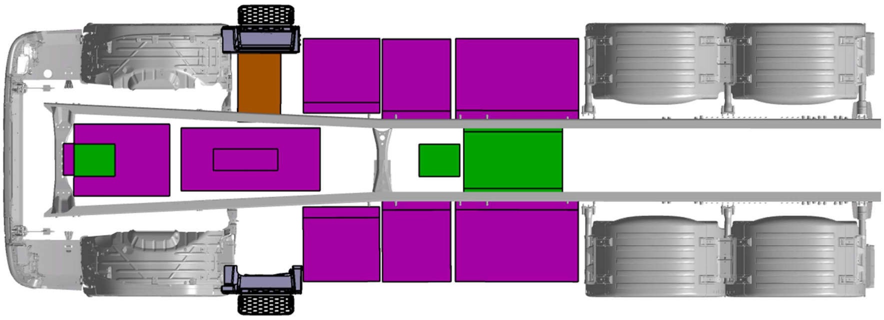


Figure 8.70 – 1750 mm Axle Distance Increase 6x2 High *GC Top View*

2250 mm Increase:
This layout could fit 7 battery packs.

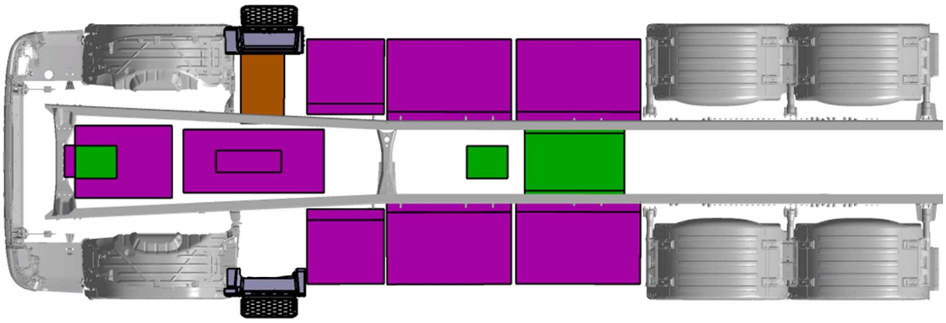


Figure 8.71 – 2250 mm Axle Distance Increase 6x2 High *GC Top View*

2900 mm Increase:
This layout could fit 8 battery packs.

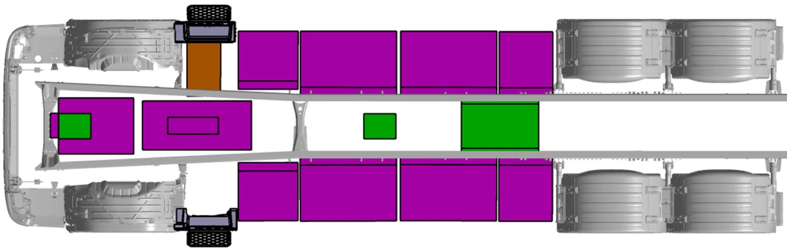


Figure 8.72 – 2900 mm Axle Distance Increase 6x2 High *GC Top View*

3400 mm Increase (Maximum):

Scenario 1:

This layout could fit 9 battery packs.

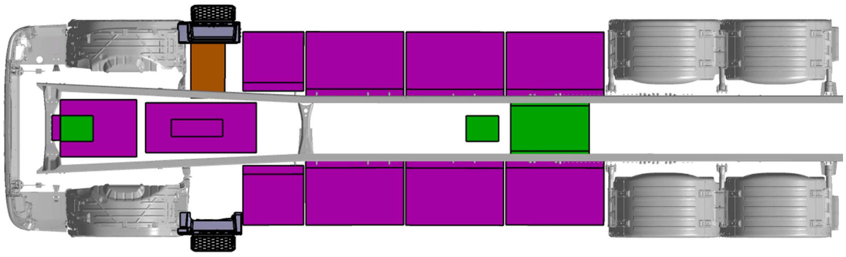


Figure 8.73 – 3400 mm Axle Distance Increase 6x2 High *GC Scenario 1 Top View*

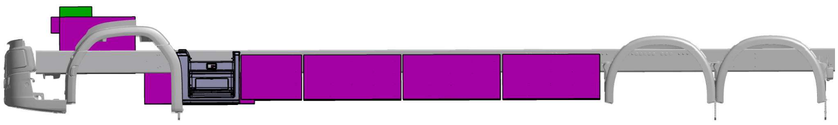


Figure 8.74 – 3400 mm Axle Distance Increase 6x2 High *GC Scenario 1 Side View*

Scenario 2:

This layout could fit 9 battery packs.

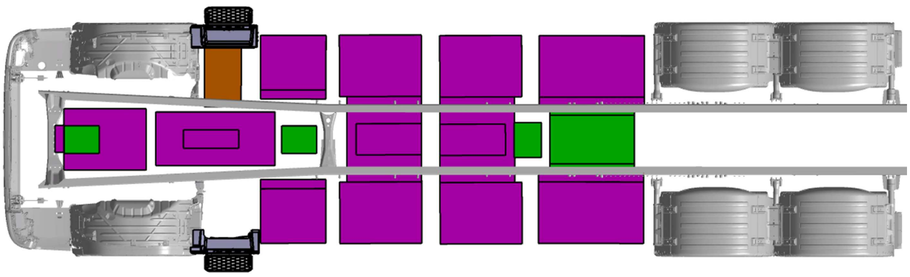


Figure 8.75 – 3400 mm Axle Distance Increase 6x2 High *GC Scenario 2 Top View*

8.1.1.3.3. Compilation

The gray box represents if the AD was not possible for that GC.

	6x2	
AD [mm]	High GC	Low GC
2950	2	3
3400	4	4
3750		6
4050	5	
4400		7
4650		8
4700	6	
5200	7	
5300		9
5550		10
5850	8	
6250	9	11

Figure 8.76 – Compilation of Battery Packs per Axel Distance for 6x2 Scenario

8.1.2. 6x2/4

8.1.2.1. CD Low GC

<u>None:</u>
This layout could fit 3 battery packs.

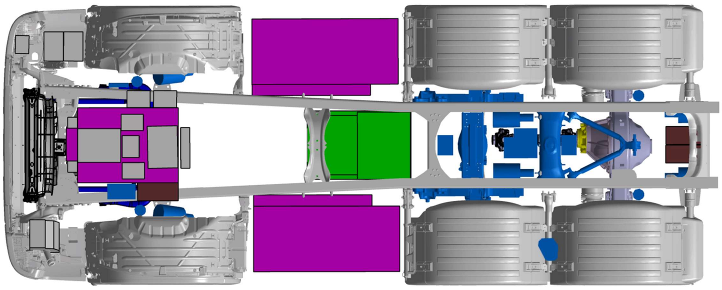


Figure 8.77 – 6x2/4 CD Low GC None

<u>Compressed Air:</u>
This layout could fit 3 battery packs.

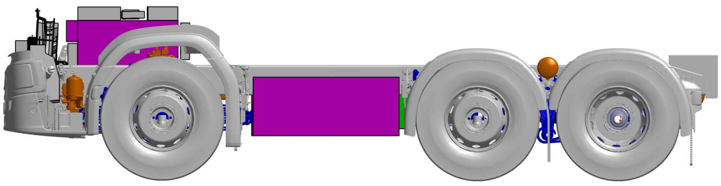


Figure 8.78 – 6x2/4 CD Low GC Compressed Air Side View

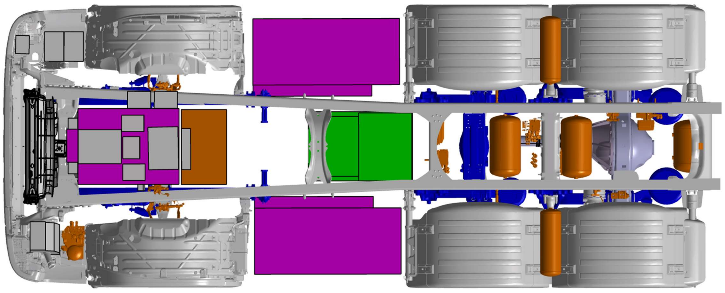


Figure 8.79 – 6x2/4 CD Low GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 3 battery packs.

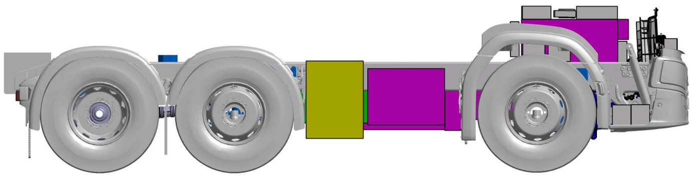


Figure 8.80 – 6x2/4 CD Low GC Hydraulic PTO Side View

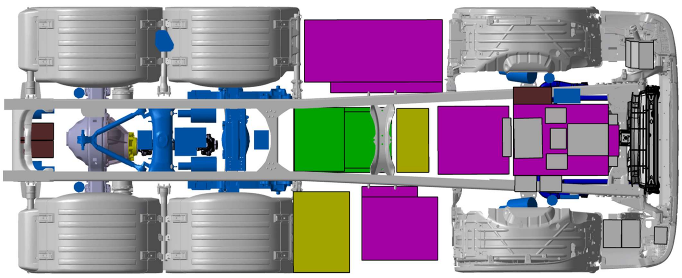


Figure 8.81 – 6x2/4 CD Low GC Hydraulic PTO Top View

Both:
This layout could fit 3 battery packs.

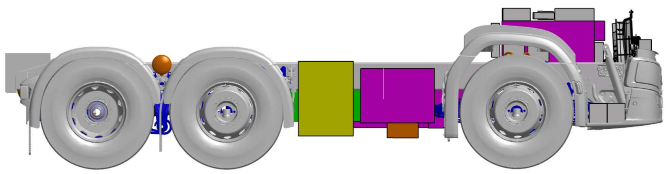


Figure 8.82 – 6x2/4 CD Low GC Both Side View

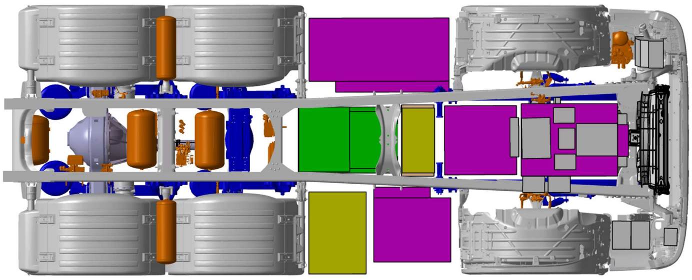


Figure 8.83 – 6x2/4 CD Low GC Both Top View

8.1.2.2. CD High GC

<u>None:</u>
This layout could fit 3 battery packs.

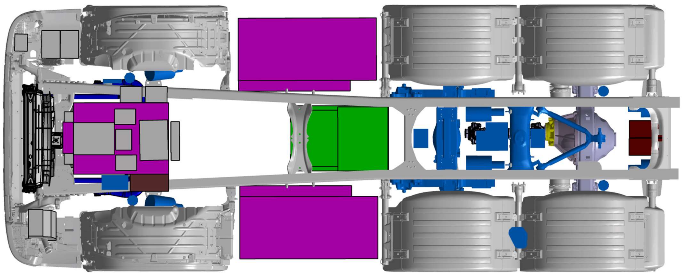


Figure 8.84 – 6x2/4 CD High GC None Top View

<u>Compressed Air:</u>
This layout could fit 3 battery packs.

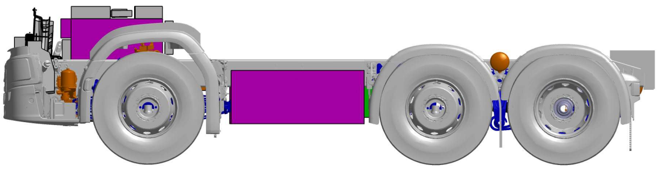


Figure 8.85 – 6x2/4 CD High GC Compressed Air Side View

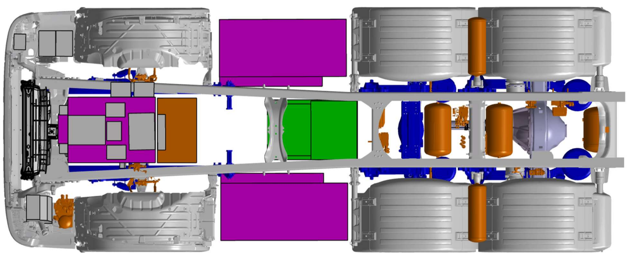


Figure 8.86 – 6x2/4 CD High GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 2 battery packs.

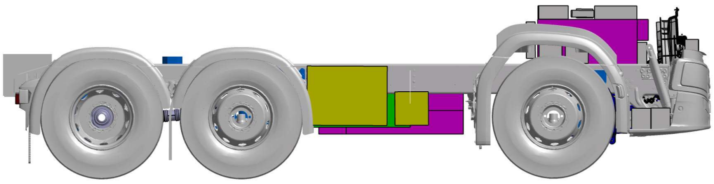


Figure 8.87 – 6x2/4 CD High GC hydraulic PTO Side View

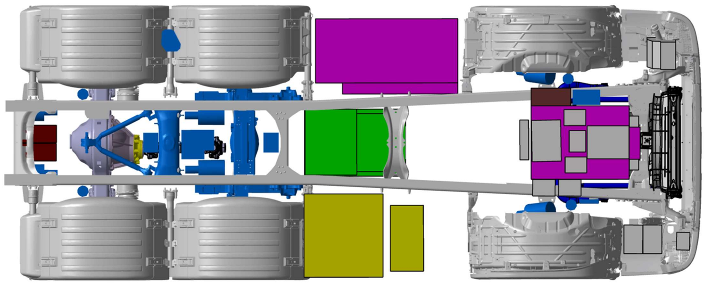


Figure 8.88 – 6x2/4 CD High GC Hydraulic PTO Top View

Both:
This layout could fit 2 battery packs.

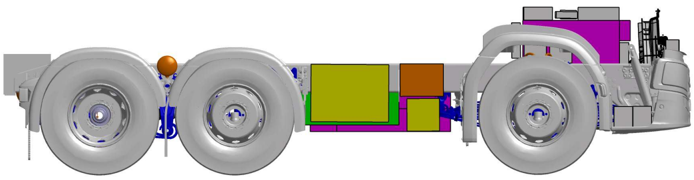


Figure 8.89 – 6x2/4 CD High GC Both Side View

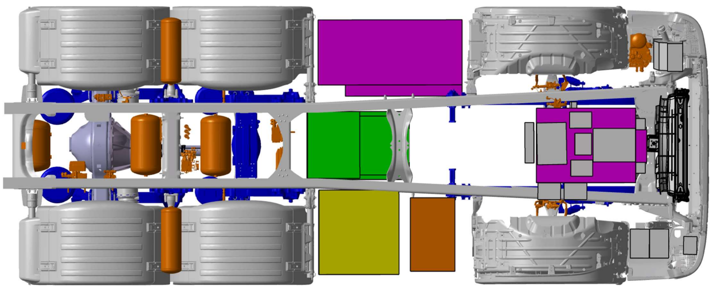


Figure 8.90 – 6x2/4 CD High GC Both Top View

8.1.2.3. E-Axle Low GC

None:
This layout could fit 4 battery packs.

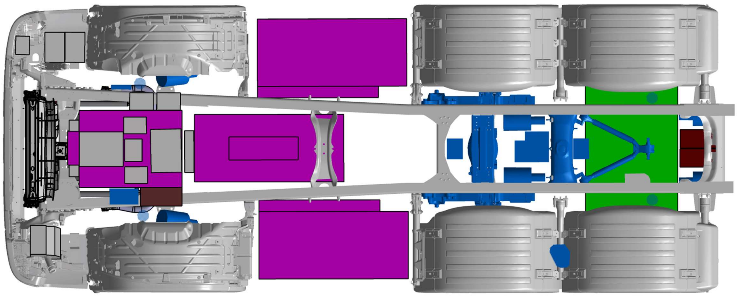


Figure 8.91 – 6x2/4 E-Axle Low GC None Top View

Compressed Air:
This layout could fit 3 battery packs.

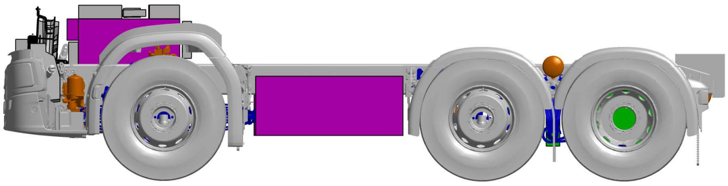


Figure 8.92 – 6x2/4 E-Axle Low GC Compressed Air Side View

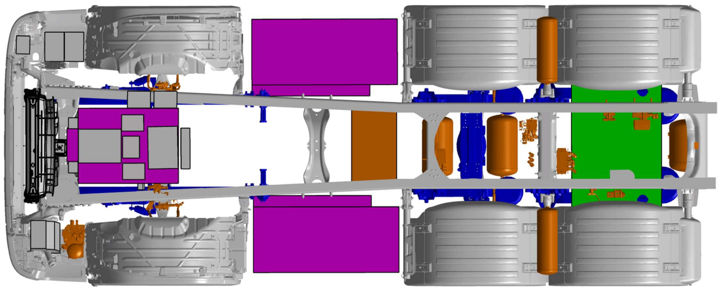


Figure 8.93 – 6x2/4 E-Axle Low GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 3 battery packs.

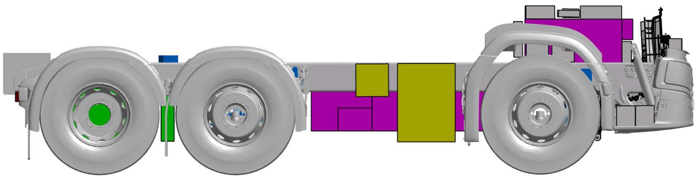


Figure 8.94 – 6x2/4 E-Axle Low GC Hydraulic PTO Side View

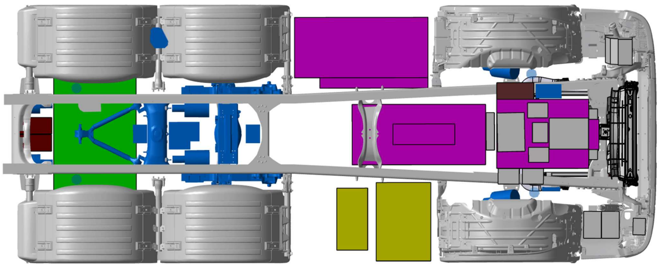


Figure 8.95 – 6x2/4 E-Axle Low GC Hydraulic PTO Top View

Both:
This layout could fit 3 battery packs.

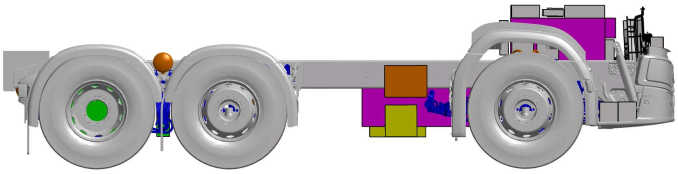


Figure 8.96 – 6x2/4 E-Axle Low GC Both Side View

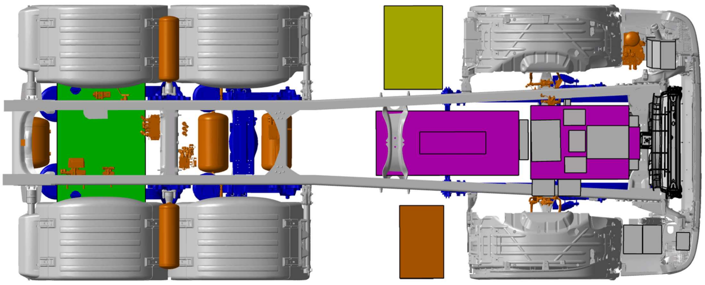


Figure 8.97 – 6x2/4 E-Axle Low GC Both Top View

8.1.2.4. E-axle High GC

None:
This layout could fit 4 battery packs.

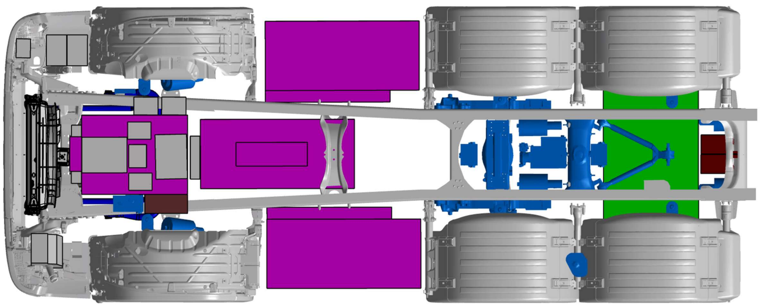


Figure 8.98 – 6x2/4 E-Axle High GC None Top View

Compressed Air:
This layout could fit 3 battery packs.

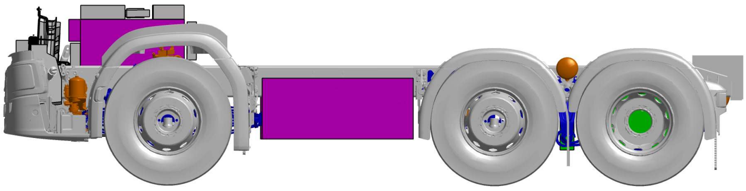


Figure 8.99 – 6x2/4 E-Axle High GC Compressed Air Side View

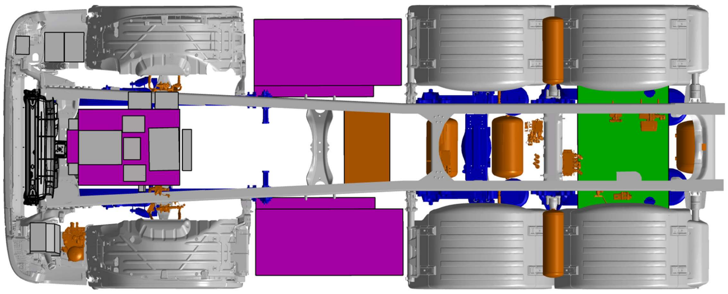


Figure 8.100 – 6x2/4 E-Axle High GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 3 battery packs.

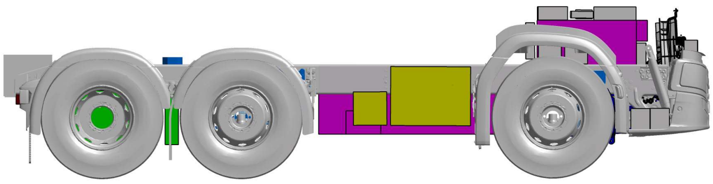


Figure 8.101 – 6x2/4 E-Axle High GC Hydraulic PTO Side View

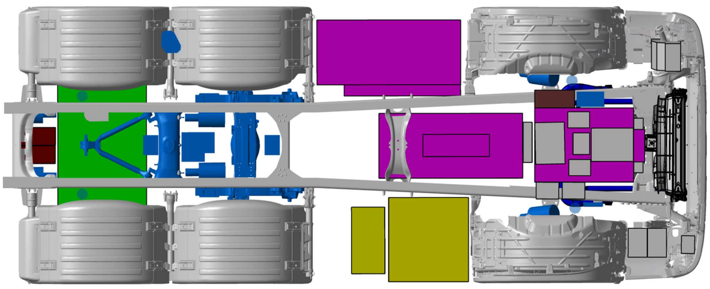


Figure 8.102 – 6x2/4 E-Axle High GC Hydraulic PTO Top View

Both:
This layout could fit 2 battery packs.

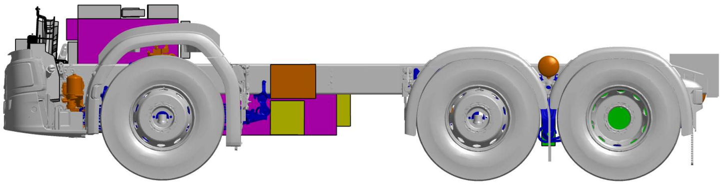


Figure 8.103 – 6x2/4 E-Axle High GC Both Side View

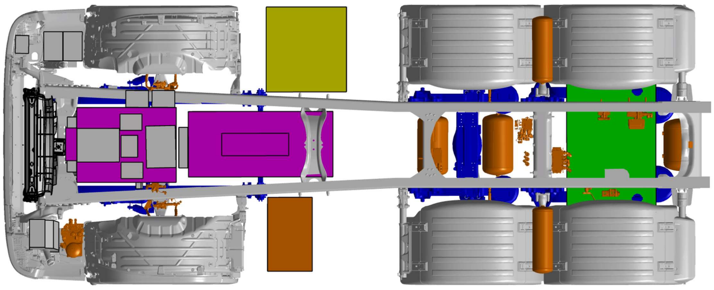


Figure 8.104 – 6x2/4 E-Axle High GC Both Top View

8.1.2.5. Boarding Step Scenarios

8.1.2.5.1. CD Low GC

<u>None:</u>
This layout could fit 3 battery packs.

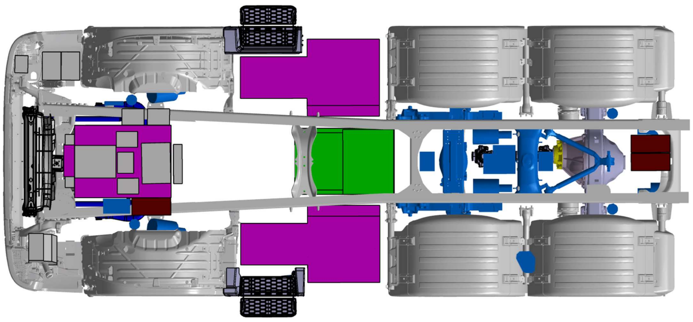


Figure 8.105 – Boarding Steps 6x2/4 CD Low GC None Top View

<u>Compressed Air:</u>
This layout could fit 3 battery packs.

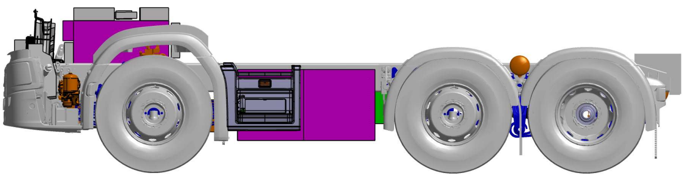


Figure 8.106 – Boarding Steps 6x2/4 CD Low GC Compressed Air Side View

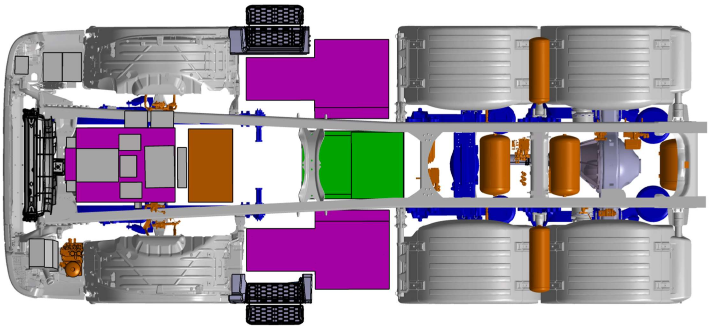


Figure 8.107 – Boarding Steps 6x2/4 CD Low GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 2 battery packs.

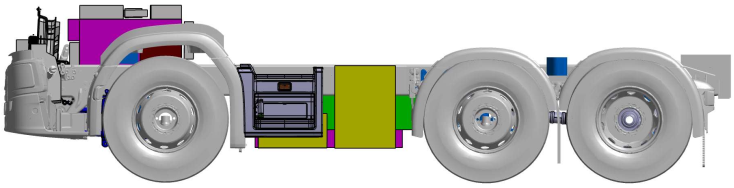


Figure 8.108 – Boarding Steps 6x2/4 CD Low GC Hydraulic PTO Side View

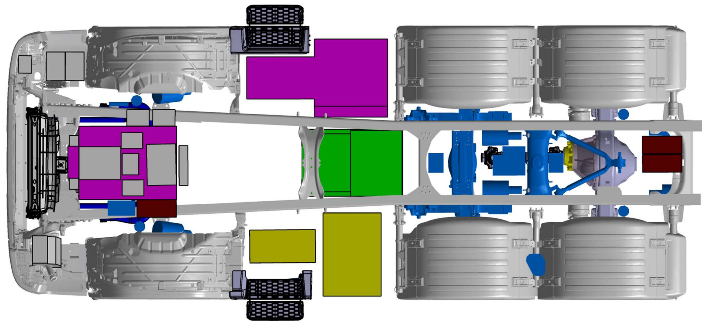


Figure 8.109 – Boarding Steps 6x2/4 CD Low GC Hydraulic PTO Top View

Both:
This layout could fit 2 battery packs.

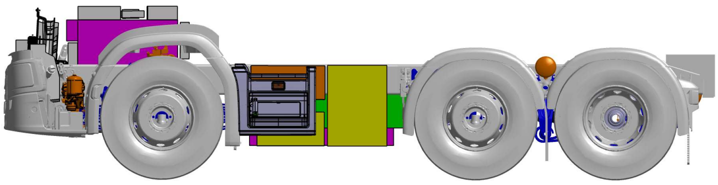


Figure 8.110 – Boarding Steps 6x2/4 CD Low GC Both Side View

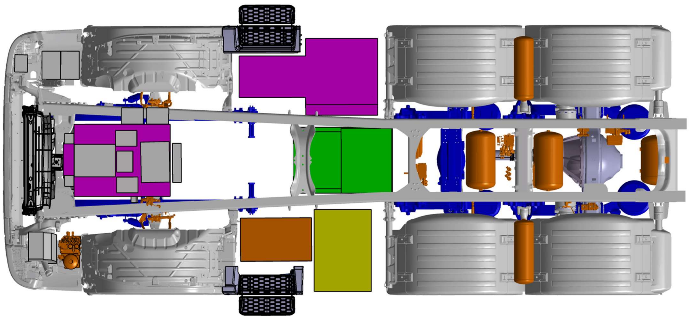


Figure 8.111 – Boarding Steps 6x2/4 CD Low GC Both Top View

8.1.2.5.2. CD High GC

None:

This layout could fit 2 battery packs.

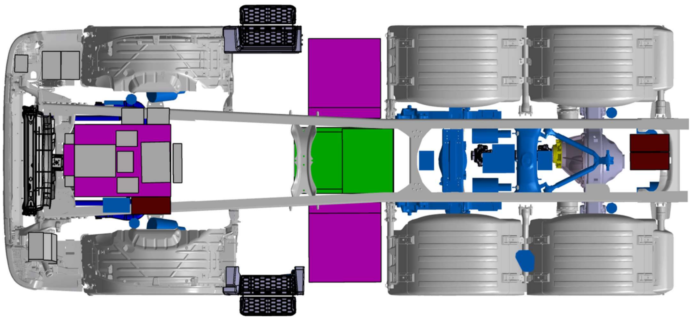


Figure 8.112 – Boarding Steps 6x2/4 CD High GC None Top View

Compressed Air:

This layout could fit 2 battery packs.

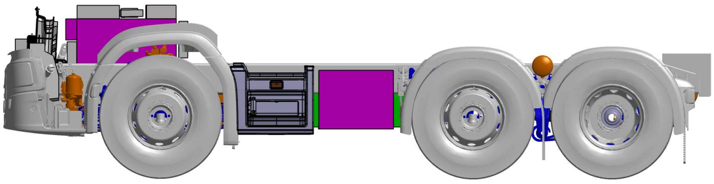


Figure 8.113 – Boarding Steps 6x2/4 CD High GC Compressed Air Side View

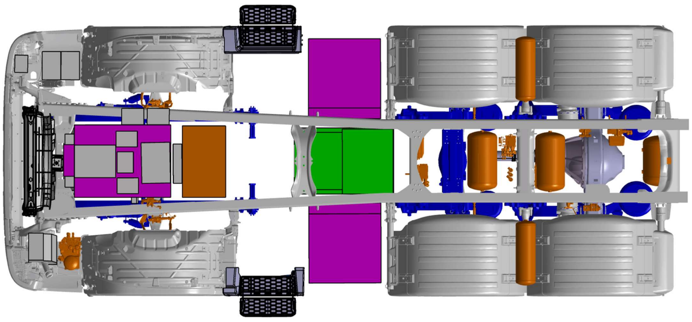


Figure 8.114 – Boarding Steps 6x2/4 CD High GC Compressed Air Top View

Hydraulic PTO:
This layout could fit 2 battery packs.

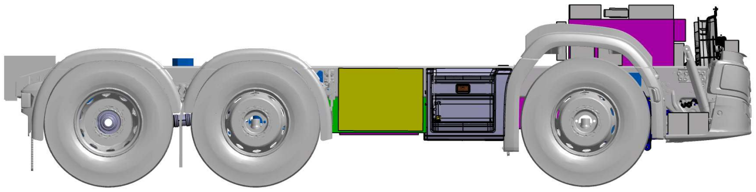


Figure 8.115 – Boarding Steps 6x2/4 CD High GC Hydraulic PTO Side View

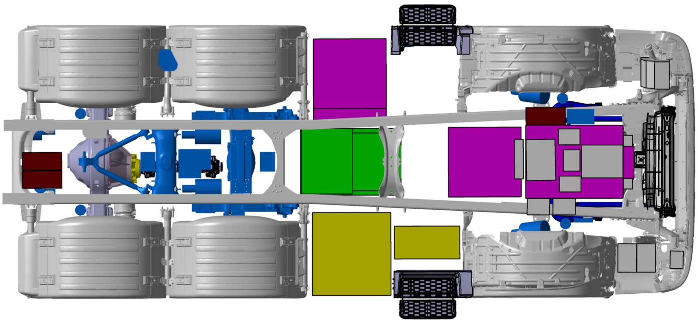


Figure 8.116 – Boarding Steps 6x2/4 CD High GC Hydraulic PTO Top View

Both:
This layout could fit 2 battery packs.

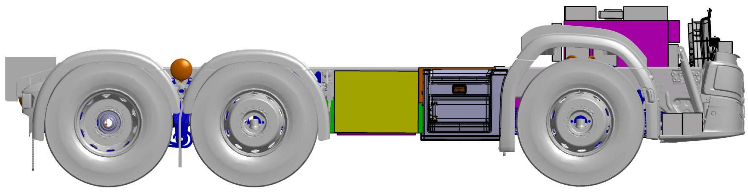


Figure 8.117 – Boarding Steps 6x2/4 CD High GC Both Side View

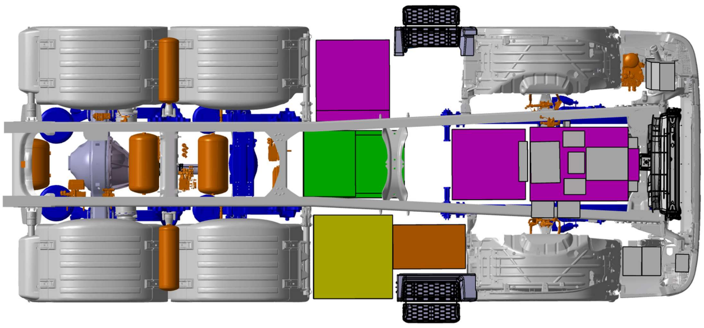


Figure 8.118 – Boarding Steps 6x2/4 CD High GC Both Top View

8.1.2.5.3. E-Axle Low GC

<u>None:</u>
This layout could fit 4 battery packs.

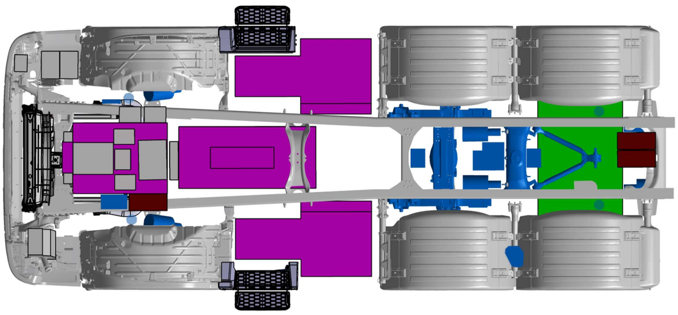


Figure 8.119 – Boarding Steps 6x2/4 E-Axle Low GC None Top View

<u>Compressed Air:</u>
This layout could fit 3 battery packs.

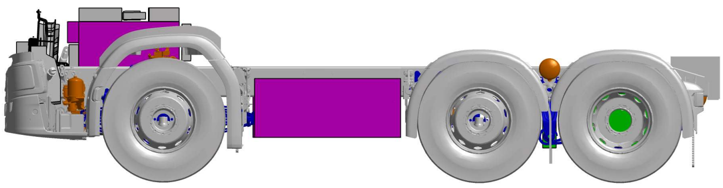


Figure 8.120 – Boarding Steps 6x2/4 E-Axle Low GC Compressed Air Side View

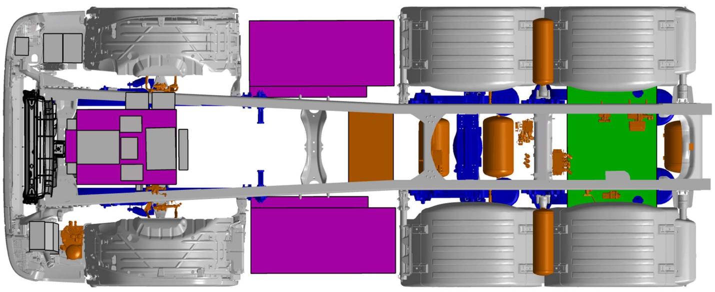


Figure 8.121 – Boarding Steps 6x2/4 E-Axle Low GC Compressed Air Top View

<u>Hydraulic PTO:</u>
This layout could fit 3 battery packs.

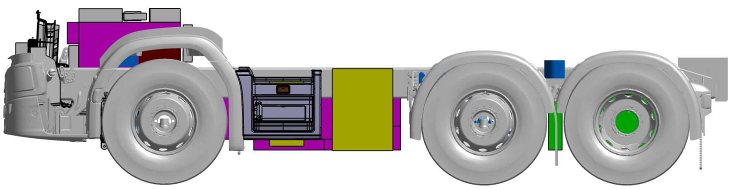


Figure 8.122 – Boarding Steps 6x2/4 E-Axle Low GC Hydraulic PTO Side View

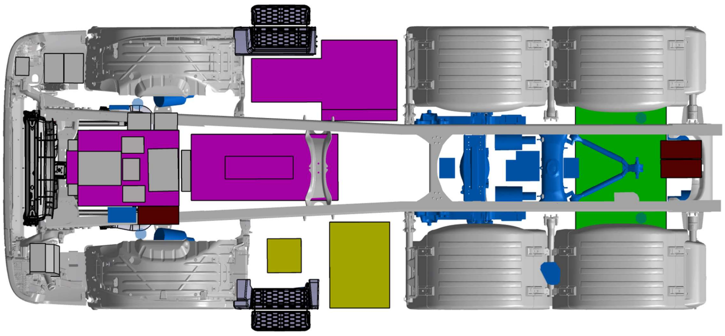


Figure 8.123 – Boarding Steps 6x2/4 E-Axle Low GC Hydraulic PTO Top View

Both:
This layout could fit 2 battery packs.

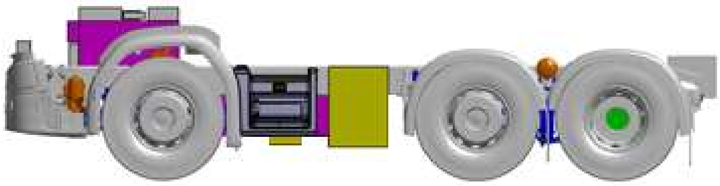


Figure 8.124 – Boarding Steps 6x2/4 E-Axle Low GC Both Side View

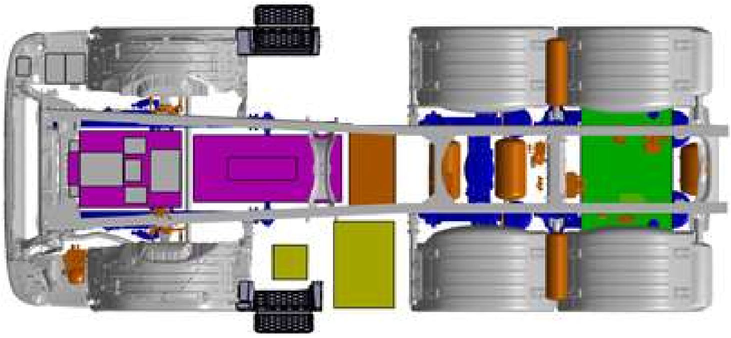


Figure 8.125 – Boarding Steps 6x2/4 E-Axle Low GC Both Top View

8.1.2.5.4. E-Axle High GC

None:
This layout could fit 3 battery packs.

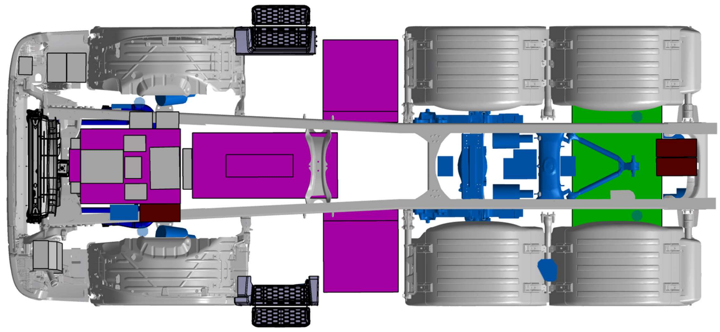


Figure 8.126 – Boarding Steps 6x2/4 E-Axle High GC None Top View

Compressed Air:
3 battery packs.

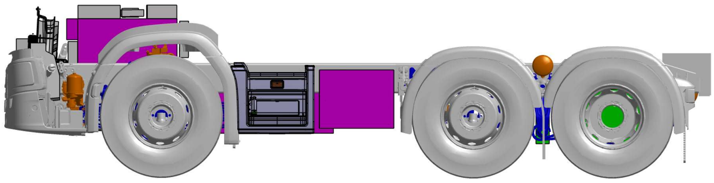


Figure 8.127 – Boarding Steps 6x2/4 E-Axle High GC Compressed Air Side View

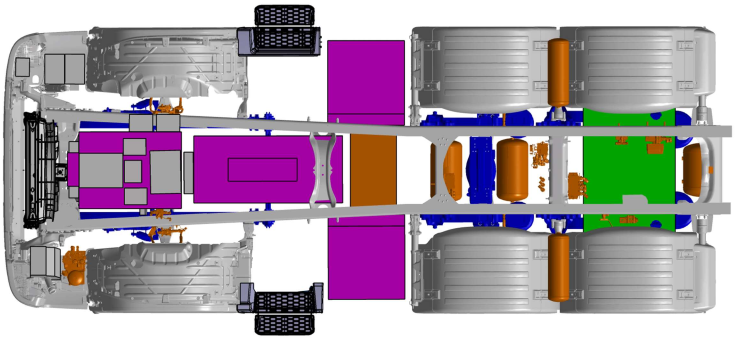


Figure 8.128 – Boarding Steps 6x2/4 E-Axle High GC Compressed Air Top View

Hydraulic PTO:
2 battery packs.

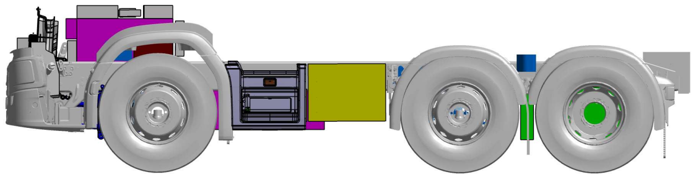


Figure 8.129 – Boarding Steps 6x2/4 E-Axle High GC Hydraulic PTO Side View

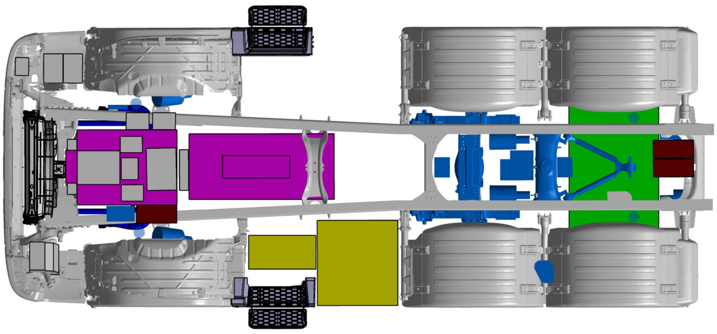


Figure 8.130 – Boarding Steps 6x2/4 E-Axle High GC Hydraulic PTO Top View

Both:
2 battery packs.

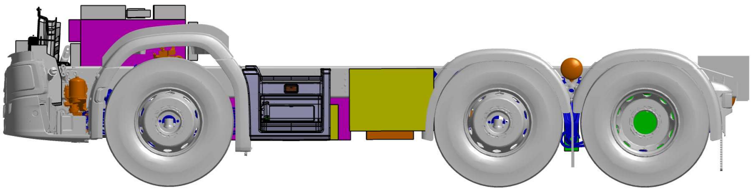


Figure 8.131– Boarding Steps 6x2/4 E-Axle High GC Both Side View

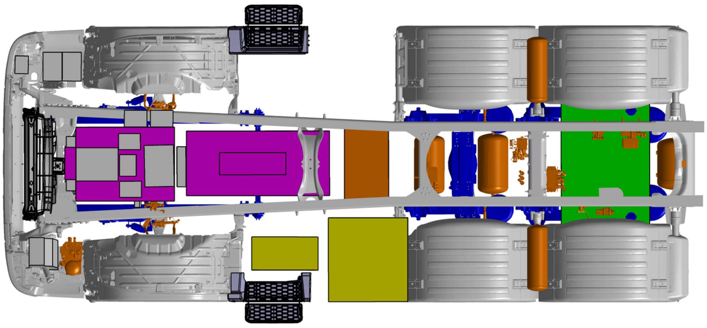


Figure 8.132 – Boarding Steps 6x2/4 E-Axle High GC Both Top View

8.1.2.6. Increased Axle Distance

8.1.2.6.1. Low GC

0 mm:

3 battery packs.

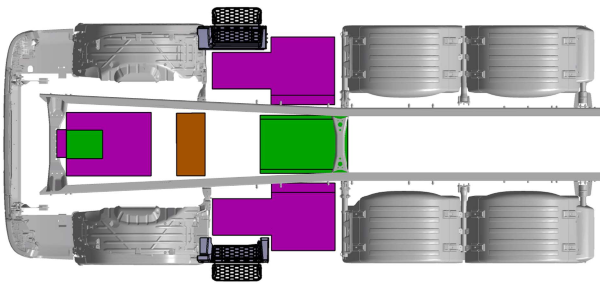


Figure 8.133 – 0 mm Axle Distance Increase 6x2/4 Low GC Top View

300 mm:

4 battery packs.

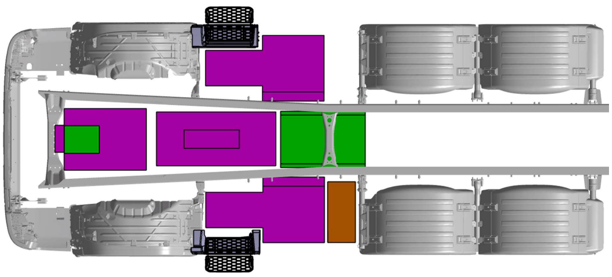


Figure 8.134 – 300 mm Axle Distance Increase 6x2/4 Low GC Top View

650 mm:
5 battery packs.

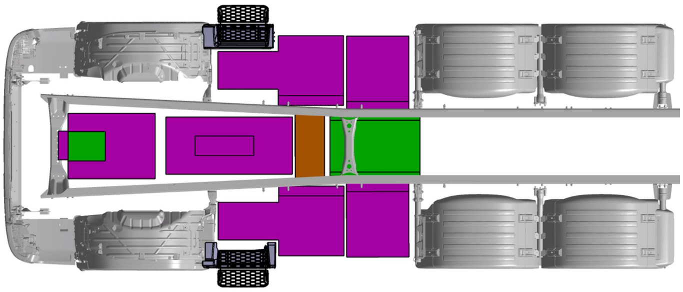


Figure 8.135 – 650 mm Axle Distance Increase 6x2/4 Low GC Top View

950 mm:
6 battery packs.

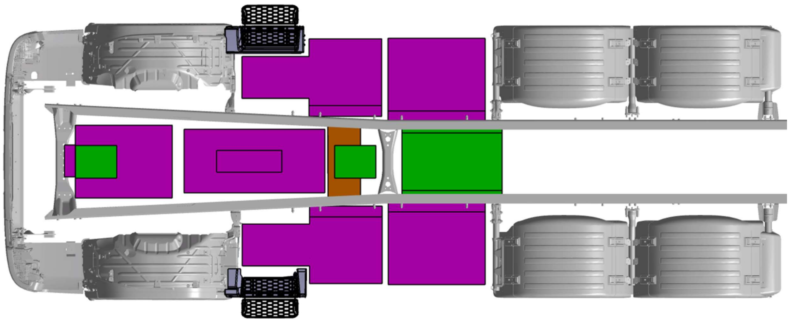


Figure 8.136 – 950 mm Axle Distance Increase 6x2/4 Low GC Top View

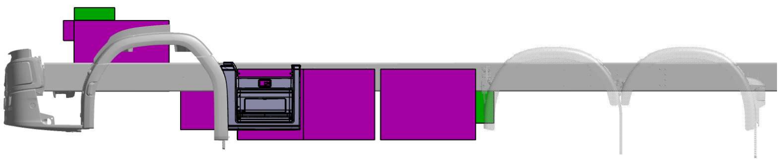


Figure 8.137 – 950 mm Axle Distance Increase 6x2/4 Low GC Side View

8.1.2.6.2. High GC

0 mm:
2 battery packs.

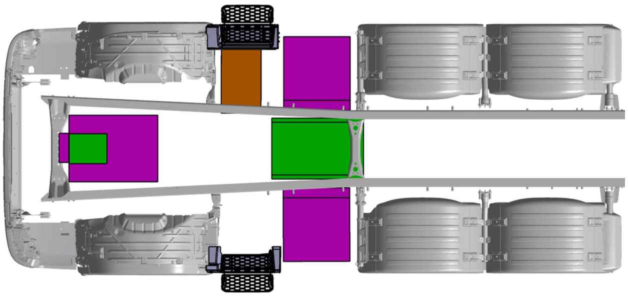


Figure 8.138 – 0 mm Axle Distance Increase 6x2/4 High GC Top View

300 mm:
3 battery packs.

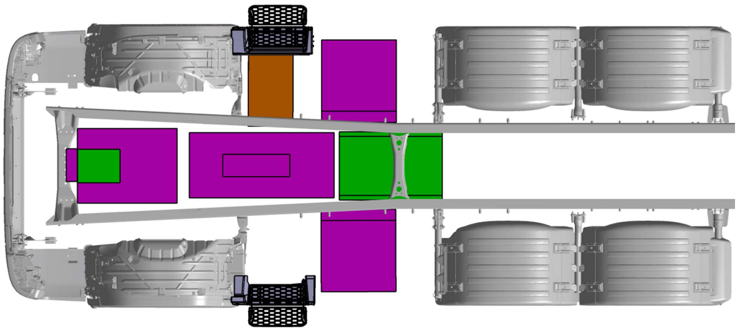


Figure 8.139 – 300 mm Axle Distance Increase 6x2/4 High GC Top View

600 mm:
4 battery packs.

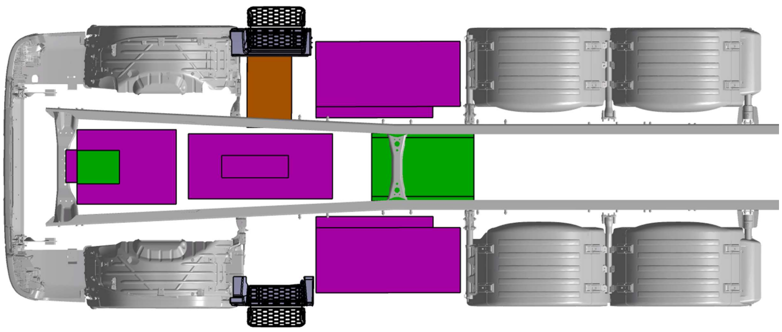


Figure 8.140 – 600 mm Axle Distance Increase 6x2/4 High GC Top View

1250 mm:
5 battery packs

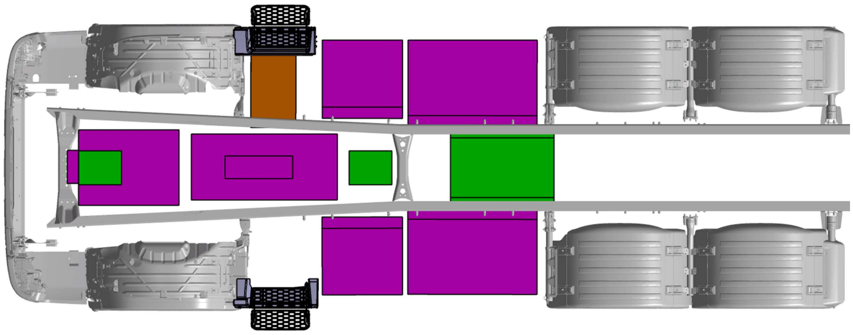


Figure 8.141 – 1250 mm Axle Distance Increase 6x2/4 High GC Top View

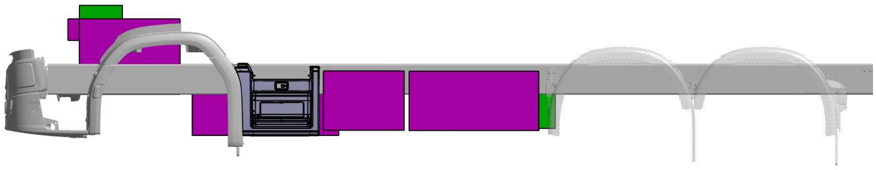


Figure 8.142 – 1250 mm Axle Distance Increase 6x2/4 High GC Side View

8.1.2.6.3. Compilation

	6x2/4	
AD [mm]	High GC	Low GC
4050	2	3
4350	3	4
4650	4	
4700		5
5000		6
5300	5	

Figure 8.143 – Compilation of Battery Packs per Axel Distance for 6x2/4 Scenario

8.1.3. 8x4

8.1.3.1. CD Low GC

None:
Number of battery packs: 2.

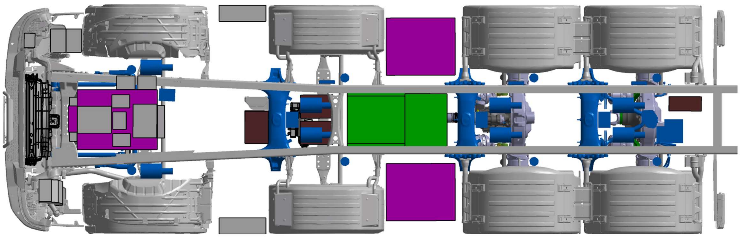


Figure 8.144 – 8x4 CD Low GC None Top View

Compressed Air:
Number of battery packs: 2.

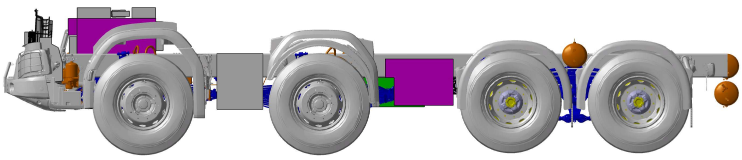


Figure 8.145 – 8x4 CD Low GC Compressed Air Side View

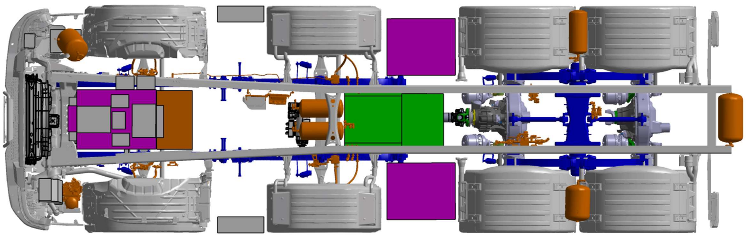


Figure 8.146 – 8x4 CD Low GC Compressed Air Top View

Hydraulic PTO:
Number of battery packs: 1.

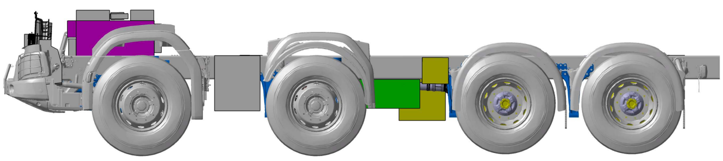


Figure 8.147 – 8x4 CD Low GC Hydraulic PTO Side View

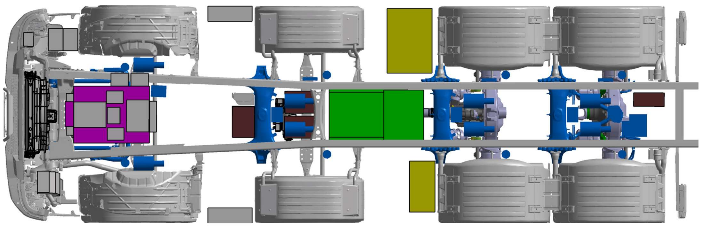


Figure 8.148 – 8x4 CD Low GC Hydraulic PTO Top View

Both:
Number of battery packs: 1.

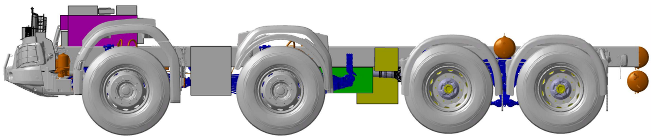


Figure 8.149 – 8x4 CD Low GC Both Side View

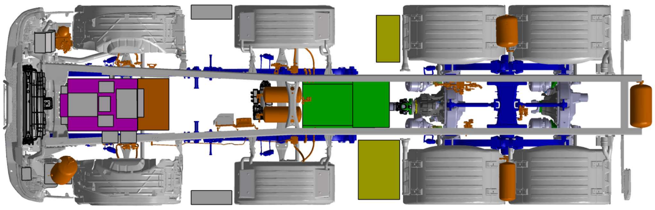


Figure 8.150 – 8x4 CD Low GC Both Top View

8.1.3.2. CD High Ground Clearance

None:
Number of battery packs: 2.

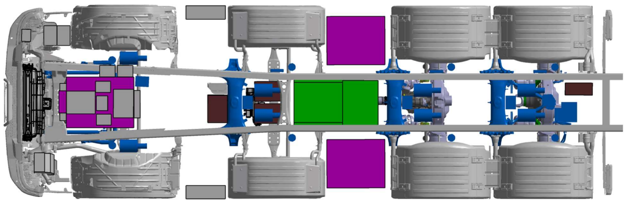


Figure 8.151 – 8x4 CD High GC None Top View

Compressed Air:
Number of battery packs: 2.

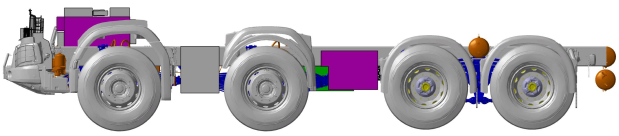


Figure 8.152 – 8x4 CD High GC Compressed Air Side View

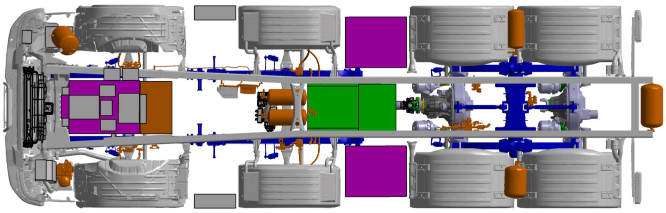


Figure 8.153 – 8x4 CD High GC Compressed Air Top View

<u>Hydraulic PTO:</u>
Number of battery packs: 1.

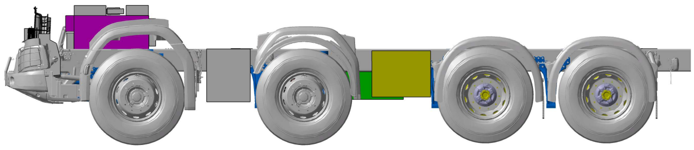


Figure 8.154 – 8x4 CD High GC Hydraulic PTO Side View

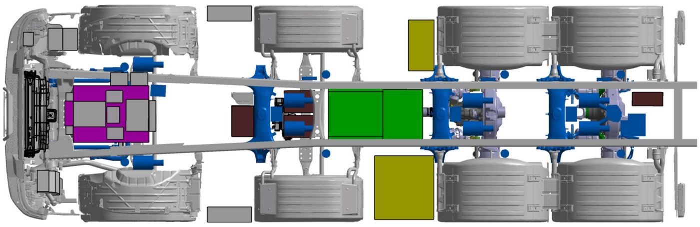


Figure 8.155 – 8x4 CD High GC Hydraulic PTO Top View

<u>Both:</u>
Number of battery packs: 1.

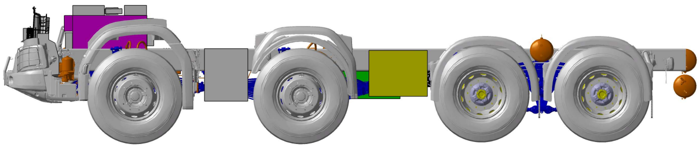


Figure 8.156 – 8x4 CD High GC Both Side View

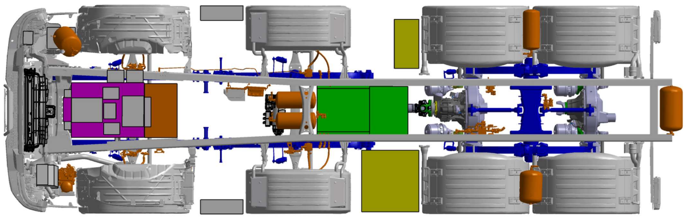


Figure 8.157 – 8x4 CD High GC Both Top View

8.1.3.3. E-Axle Low GC

<u>None:</u>
Number of battery packs: 3.

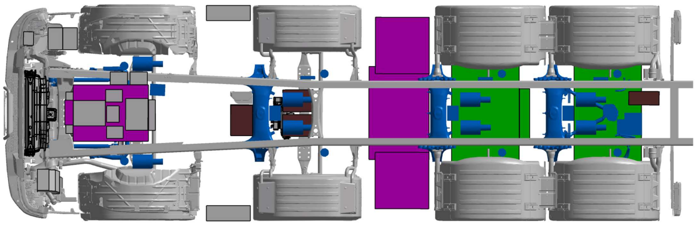


Figure 8.158 – 8x4 E-Axle Low GC None Top View

Compressed Air:
Number of battery packs: 3.

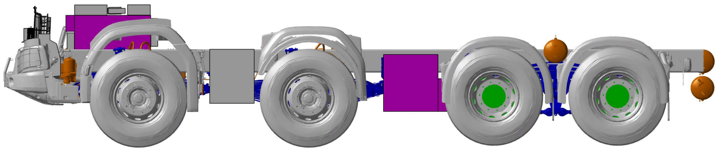


Figure 8.159 – 8x4 E-Axle Low GC Compressed Air Side View

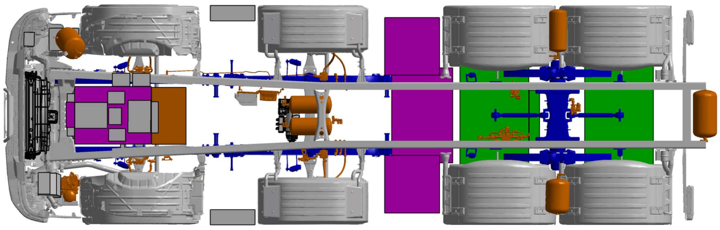


Figure 8.160 – 8x4 E-Axle Low GC Compressed Air Top View

Hydraulic PTO:
Number of battery packs: 2.

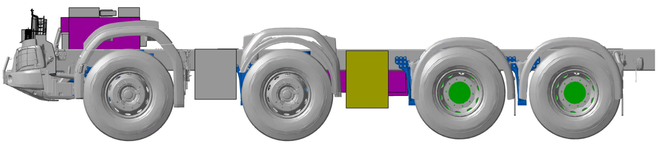


Figure 8.161 – 8x4 E-Axle Low GC Hydraulic PTO Side View

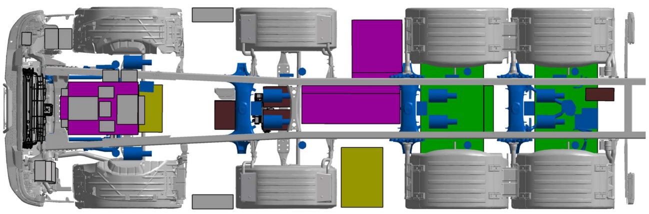


Figure 8.162 – 8x4 E-Axle Low GC Hydraulic PTO Top View

Both:
Number of battery packs: 2.

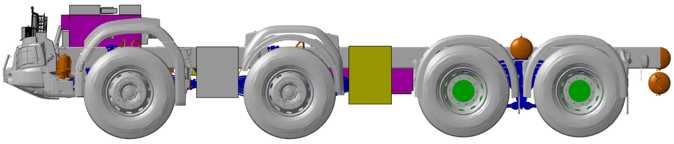


Figure 8.163 – 8x4 E-Axle Low GC Both Side View

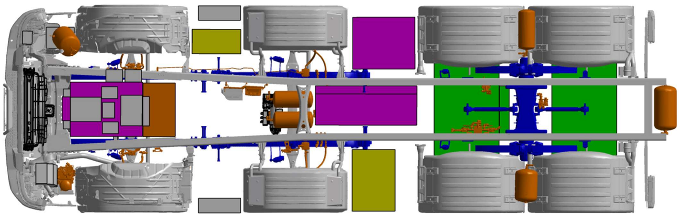


Figure 8.164 – 8x4 E-Axle Low GC Both Top View

8.1.3.4. E-Axle High GC

<u>None:</u>
Number of battery packs: 2.

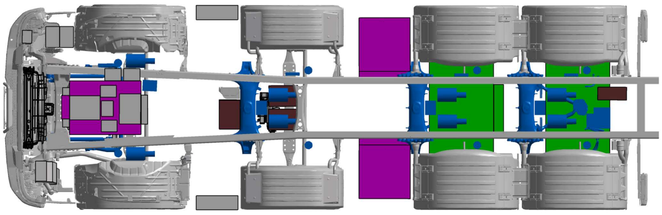


Figure 8.165 – 8x4 E-Axle High GC None Top View

<u>Compressed Air:</u>
Number of battery packs: 2.

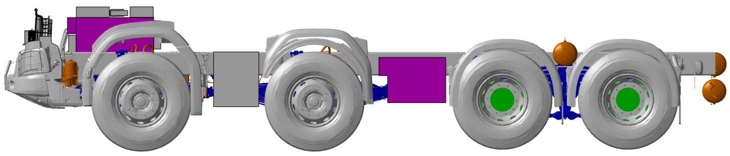


Figure 8.166 – 8x4 E-Axle High GC Compressed Air Side View

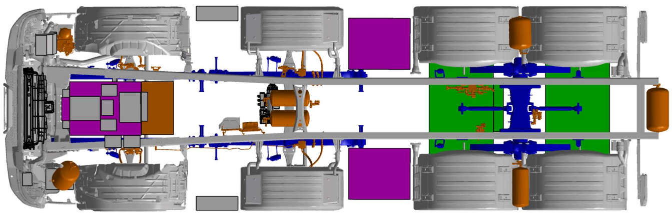


Figure 8.167 – 8x4 E-Axle High GC Compressed Air Top View

<u>Hydraulic PTO:</u>
Number of battery packs: 2.

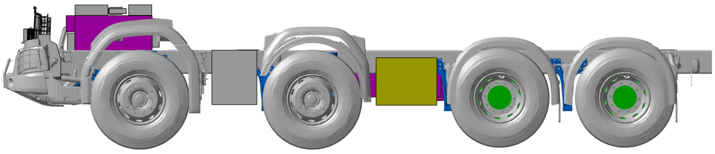


Figure 8.168 – 8x4 E-Axle High GC Hydraulic PTO Side View

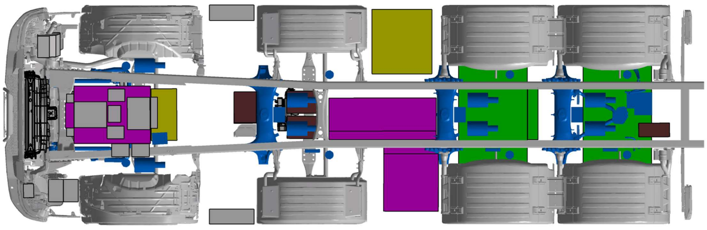


Figure 8.169 – 8x4 E-Axle High GC Hydraulic PTO Top View

Both:
Number of battery packs: 2.

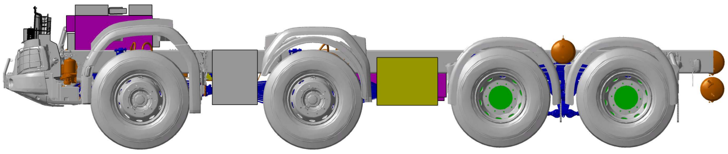


Figure 8.170 – 8x4 E-Axle High GC Both Side View

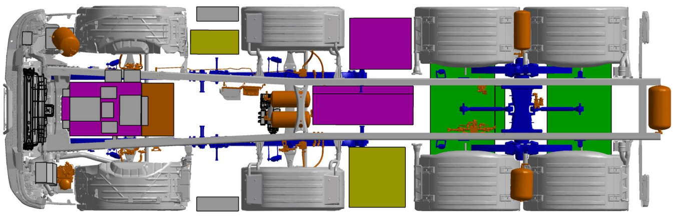


Figure 8.171 – 8x4 E-Axle High GC Both Top View

8.1.3.5. Increased Axle Distance

8.1.3.5.1. Low GC

150:
Number of battery packs: 2.

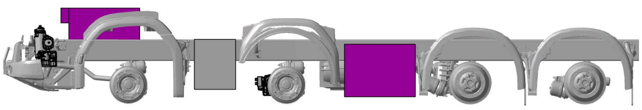


Figure 8.172 – 150 mm Axle Distance Increase 8x4 Low GC Side View

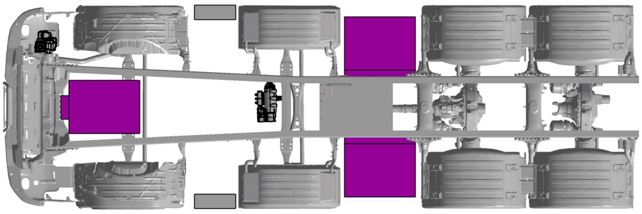


Figure 8.173 – 150 mm Axle Distance Increase 8x4 Low GC Top View

450:

Number of battery packs: 3.

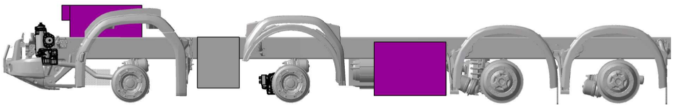


Figure 8.174 – 450 mm Axle Distance Increase 8x4 Low GC Side View

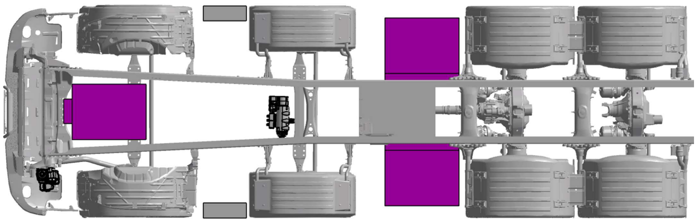


Figure 8.175 – 450 mm Axle Distance Increase 8x4 Low GC Top View

800:

Number of battery packs: 4.

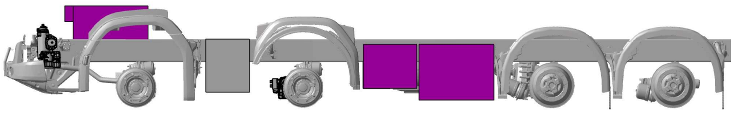


Figure 8.176 – 800 mm Axle Distance Increase 8x4 Low GC Side View

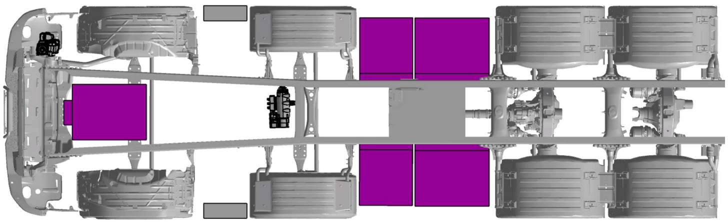


Figure 8.177 – 800 mm Axle Distance Increase 8x4 Low GC Top View

1050:

Number of battery packs: 5.

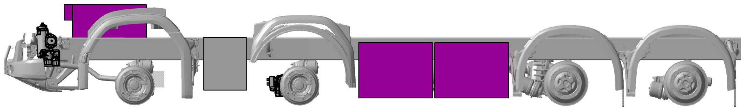


Figure 8.178 – 1050 mm Axle Distance Increase 8x4 Low GC Side View

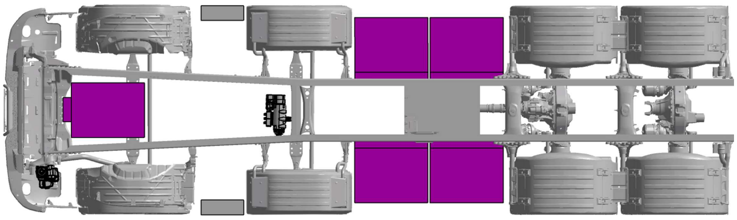


Figure 8.179 – 1050 mm Axle Distance Increase 8x4 Low GC Top View

1150:
Number of battery packs: 5.

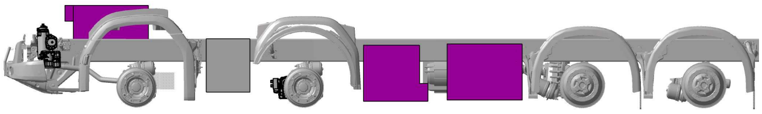


Figure 8.180 – 1150 mm Axle Distance Increase 8x4 Low GC Side View

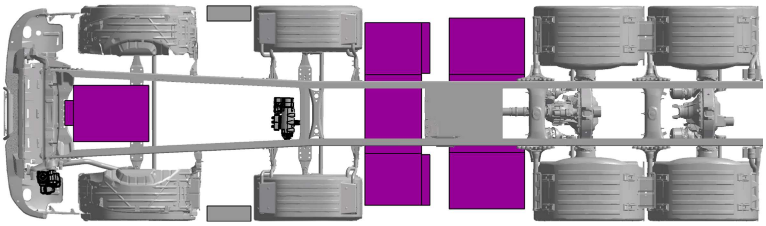


Figure 8.181 – 1150 mm Axle Distance Increase 8x4 Low GC Top View

1750:
Number of battery packs: 6.

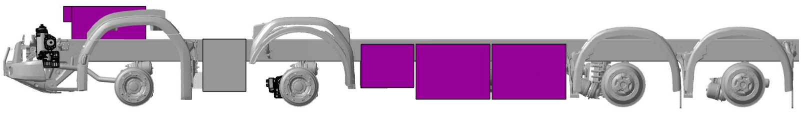


Figure 8.182 – 1750 mm Axle Distance Increase 8x4 Low GC Side View

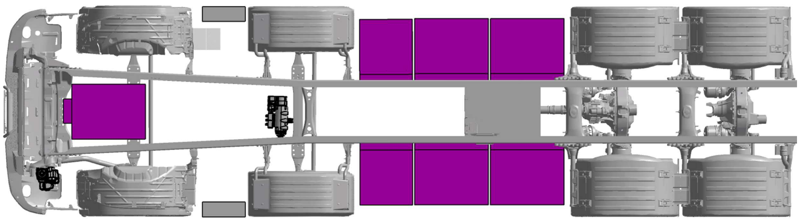


Figure 8.183 – 1750 mm Axle Distance Increase 8x4 Low GC Top View

Max AD Scenario 1:
Number of battery packs: 8.

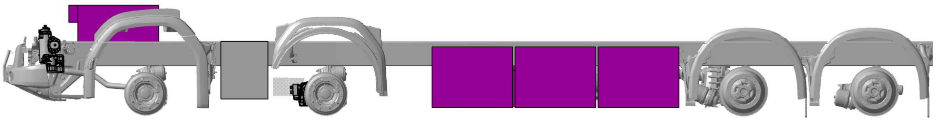


Figure 8.184 – Max Axle Distance Increase 8x4 Low GC Side View

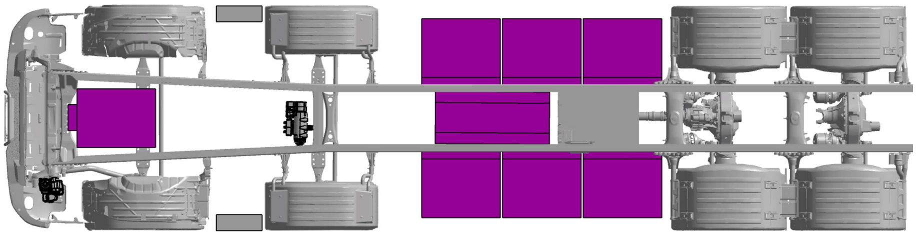


Figure 8.185 – Max Axle Distance Increase 8x4 Low GC Top View

Max AD Scenario 2:
Number of battery packs: 7.

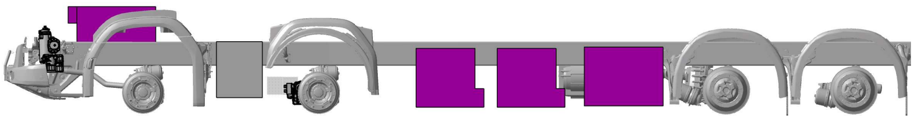


Figure 8.186 – Max Axle Distance Increase 8x4 Low GC Side View Scenario 2

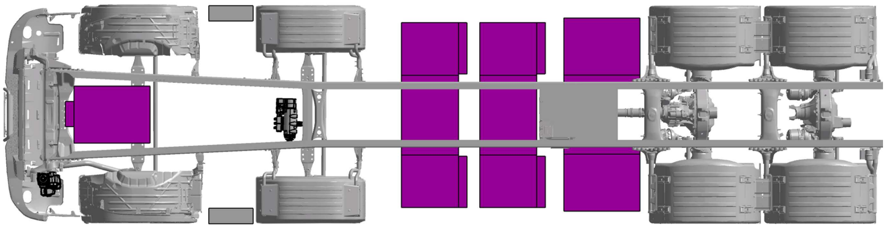


Figure 8.187 – Max Axle Distance Increase 8x4 Low GC Top View Scenario 2

8.1.3.5.2. High GC

400:
Number of battery packs: 3.

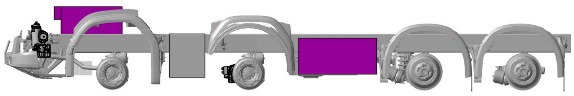


Figure 8.188 – 400 mm Axle Distance Increase 8x4 High GC Side View

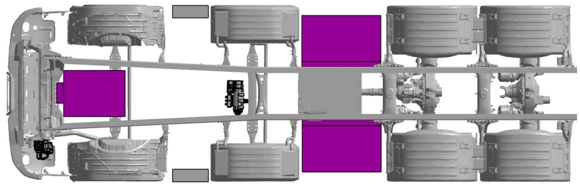


Figure 8.189 – 400 mm Axle Distance Increase 8x4 High GC Top View

<u>1050:</u>
Number of battery packs: 4.

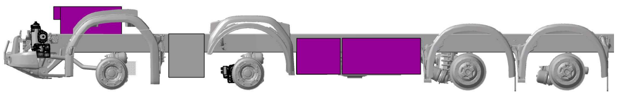


Figure 8.190 – 1050 mm Axle Distance Increase 8x4 High GC Side View

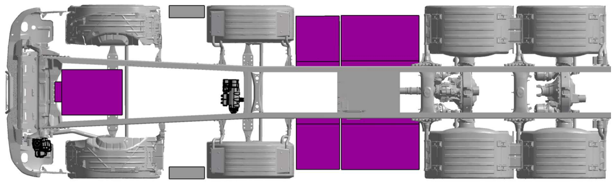


Figure 8.191 – 1050 mm Axle Distance Increase 8x4 High GC Top View

<u>1400:</u>
Number of battery packs: 5.

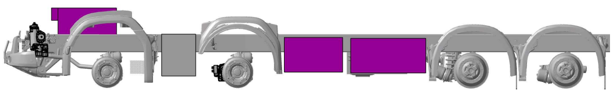


Figure 8.192 – 1400 mm Axle Distance Increase 8x4 High GC Side View

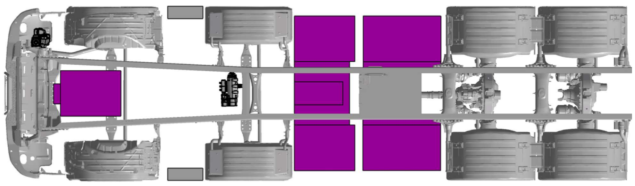


Figure 8.193 – 1400 mm Axle Distance Increase 8x4 High GC Top View

<u>1600:</u>
Number of battery packs: 5.

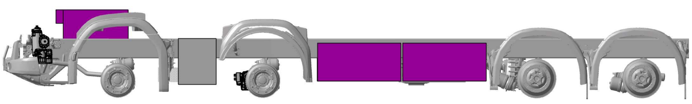


Figure 8.194 – 1600 mm Axle Distance Increase 8x4 High GC Side View

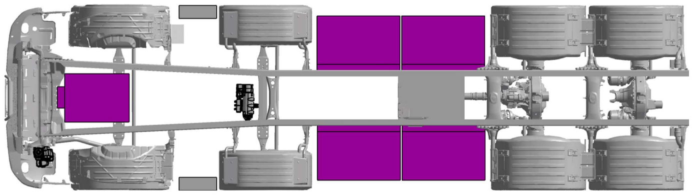


Figure 8.195 – 1600 mm Axle Distance Increase 8x4 High GC Top View

2150:
Number of battery packs: 6.

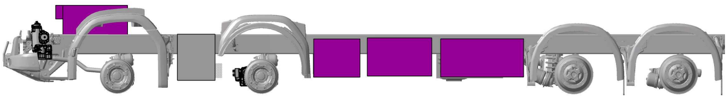


Figure 8.196 – 2150 mm Axle Distance Increase 8x4 High GC Side View

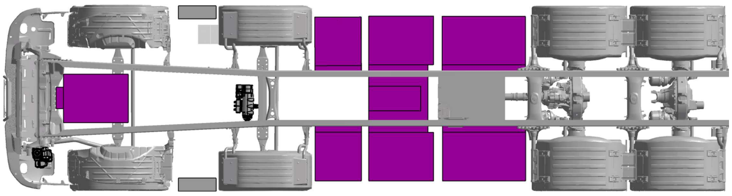


Figure 8.197 – 2150 mm Axle Distance Increase 8x4 High GC Top View

2250:
Number of battery packs: 6.

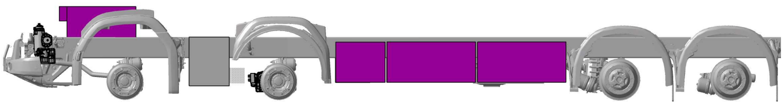


Figure 8.198– 2250 mm Axle Distance Increase 8x4 High GC Side View

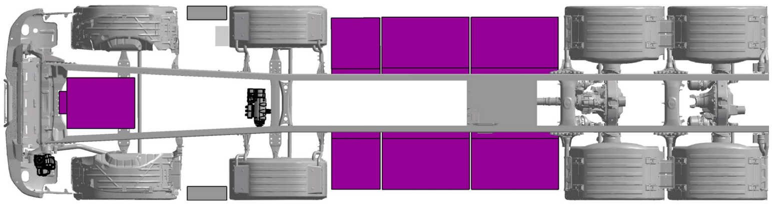


Figure 8.199 – 2250 mm Axle Distance Increase 8x4 High GC Top View

Max AD:
Number of battery packs: 7.

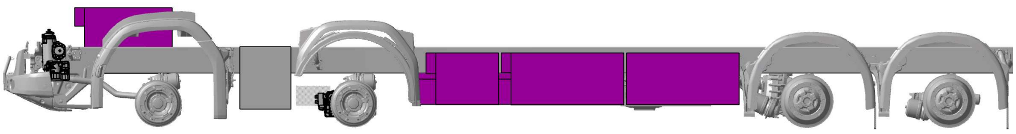


Figure 8.200 – Max Axle Distance Increase 8x4 High GC Side View

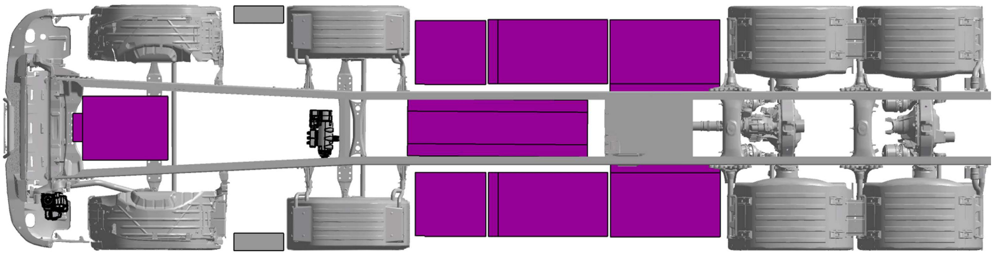


Figure 8.201 – Max Axle Distance Increase 8x4 High GC Top View

8.1.3.5.3. Compilation

	8x4	
AD [mm]	High GC	Low GC
4150	2	2
4300		3
4550	3	
4950		4
5200	4	5
5300		5
5550	5	
5750	5	
5900		6
6100	6	7
6300	6	
6400	6	
6550	7	8

Figure 8.202 – Compilation of Battery Packs per Axel Distance for 8x4 Scenario

8.2. Dimensional Regulations

Since this master thesis has been limited to focusing on the European market it must be ensured that the regulations which exist in this market are followed. Scania's internal standards should also be followed to minimize the risk of eventual market requirement problems. Size regulations will be followed during the duration of the master thesis since not enough time is available to analyze regulations relating to mass. Regulations regarding turning radius are also not analyzed in this report, since if the current wheel configurations and axle lengths are followed, then it can be assumed that the turning radius requirements are also fulfilled.

8.2.1. Size

8.2.1.1. Scania Standards

The maximum size dimensions of the trucks at Scania are maximum length 12.00 meters, maximum width 2.55 meters and maximum height 4.00 meters (Scania, 2010).

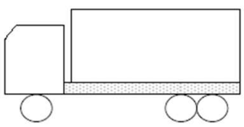
8.2.1.2. Change of EU-Regulation

There is now an EU-regulation change in process which will allow to increase the length of the trucks according to EU Directive 2015/719. With this new regulation, the length of the trucks will instead be primarily limited by the size standards of roundabouts. Due to the new regulation, Scania will be able to protrude their fronts by 200 mm. This can help to increase the potential storage space in the front of the truck. However, extended fronts will require a rounded design to ensure that the truck does not exceed the roundabout limitations. Also, due to the turning radius constraint, this potential increase of the dimensions of the trucks will be primarily regarded for tractors and not rigid trucks.

Furthermore, the axle distance for truck configuration 6x2 AD2950 can be extended by 550 mm which will help to increase the amount of potential storage space in the middle region of the truck. Likewise, the minimum axle distance for wheel configuration 6x2/4 can be extended by 150 mm. At this point there has been no analysis for wheel configuration 8x4 to suggest that the axle distance can be increased.

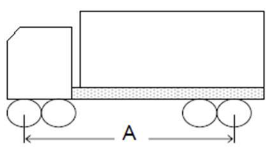
8.2.2. Total Weight

Scania's internal standards for maximum weight of their trucks can be seen in the figures below.



Three-axle motor vehicles	25 tonnes
Three-axle motor vehicles where the driving axle is fitted with twin tyres and air suspension (or equivalent), or where each driving axle is fitted with twin tyres and the maximum weight of each axle does not exceed 9,5 tonnes.	26 tonnes

Figure 8.203 – Maximum Weight Three-Axle Truck (Scania, 2010)



Four-axle motor vehicles with two steering axles where the driving axle is fitted with twin tyres and air suspension (or equivalent), or where each driving axle is fitted with twin tyres and the maximum weight of each axle does not exceed 9,5 tonnes	32 tonnes Maximum weight in tonnes may not exceed 5 times the distance *A* in meters

Figure 8.204 – Maximum Weight Four-Axle Truck (Scania, 2010)

8.2.2.1. Change of EU-Regulation

There is an EU-regulation change in process, EU Directive 2015/719, which will allow alternatively fueled trucks to increase their total weight to allow mounting of additional energy storage components. Since fully electrified trucks classifies as alternatively fueled, then this can be utilized as long as the new requirements are followed.

8.2.3. Weight Distribution

There also exists regulations regarding maximum weight distribution to axles on the trucks. A minimum of 25% of the total laden weight of the truck or truck and trailer combination must be distributed to the driving axles (Scania, 2010). Otherwise, the general maximum weight per single axle is 10 tons for non-driven axles and 11.5 tons for driven axles. For tandem axles, the maximum weight can be seen in *Figure 8.205* below.

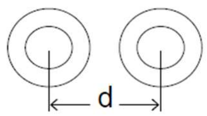
Tandem axles of motor vehicles		
	d < 1,0 m	11,5 tonnes
	1,0 m ≤ d < 1,3 m	16 tonnes
	1,3 m ≤ d < 1,8 m	18 tonnes
	1,3 m ≤ d < 1,8 and the driving axle is fitted with twin tyres and air suspension (or equivalent), or where the driving axle is fitted with twin tyres and where the maximum weight for each axle does not exceed 9,5 tonnes	19 tonnes

Figure 8.205– Maximum Weight Distribution Tandem Axles (Scania, 2010)