BIOSUN

Transport Technology for
Sustainable Intermodal Transports of Biofuel

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Preface

The BIOSUN project has been carried out within the virtual research and demonstration centre, the “Swedish Intermodal Research Centre, Sir-C”, as one of the final projects within this context. The project has been financed by the National Swedish Rail Administration and the Swedish Road Administration, which have merged together since the project was approved, now known as the Swedish Transport Administration.

The BIOSUN project is divided into six individual studies, which have been carried out by different consultants and faculties. The project team has been represented by the University of Gothenburg – School of Business, Economics and Law; WSP Group in Gothenburg; Royal Institute of Technology in Stockholm; University of National Resources and Life Sciences in Vienna and MariTerm AB in Höganäs.

The overall ambition of the project is to analyze and develop intermodal transportation solutions for biofuels used for energy purposes in power and heating plants. The project is expected to result in proposals on how intermodal transports of biofuels should be designed. The project will also develop general knowledge about intermodal transports of biofuels and knowledge about the market for biofuels, from a logistical perspective. MariTerm’s part in the study is to cover the transport technology aspects of biofuel shipments and to evaluate how these technologies can facilitate intermodal transports of biofuels.

During the study process, several reference meetings have been held, represented by the project team as well as external companies and organizations working within the bioenergy field. The aim of these meetings was to get input and comments on primary results, suggest new ideas and discuss the further development.

We also want to thank Per-Henrik Evebring at Stockarydsterminalen and Iulian Olteanu at Oresund Drydocks for supplying material to our practical tests.

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Summary

One of our greatest challenges in human history is to solve the arising climate crisis, which is an immediate result of our extensive burning of fossil fuels. If we fail to break the negative trend, irreparable damage may arise which could result in unforeseeable effects in the future. With these challenges in mind the energy transition from fossil fuels to renewable energy sources is of great importance. One step in the right direction is to use biofuel products for energy extraction, since these do not contribute to an increase of climate gases. This report has focused on suitable technologies available for intermodal transports of such products, since the transport sector has a great share of the total emissions of carbon dioxide.

What this study has shown is that there are a lot of concepts available for intermodal transports of biofuels. Some of these concepts are developed for pure bulk cargo transports while others can be used for a broader range of cargoes. What distinguishes cargo transport units intended for bulk cargoes with low density, like wood chips, is that they usually have a higher volume capacity than general cargo transport units. The problem with these units is that they could be difficult to use for intermodal transports since they tend to be optimized for either road or railway transports. Due to poor harmonization of maximum height and width dimensions in road and railway networks, there is a risk that volume optimized cargo transport units become incompatible in intermodal transport chains.

Biofuel transport operators have stated that reloading of cargo isn't considered as a major issue since it is a relatively quick and cost efficient process. A multimodal transport solution, where different cargo transport units are used for the road and railway transport legs, has great benefits when it comes to the weight and volume utilization. With such solutions it is possible to achieve a higher level of optimization since the volume is adjusted for each transport leg, which isn't possible for intermodal transport solutions. Based on this, it is difficult not to classify intermodal cargo transport units as a compromise between different interests.

Since it is difficult to change the length, width and height dimensions of the cargo transport unit without exceeding the permitted dimensions for road or railway transports, one solution might be longer vehicle combinations on road. Today, a maximum vehicle length of 25.25 m is allowed on Swedish roads, which is equal to a truck with three 20 ft. containers. If the permitted length could be increased to 30 m, a vehicle length which is now tested on Swedish roads, one additional unit could be loaded. In such a concept, the overall utilization would increase as well as the fuel efficiency.

For easy handling, the cargo transport unit should be of "open top type", where cargo can be loaded from above. The discharge should be made either by rotating the unit upside down or through doors on one side.

It has been shown in practical tests that freezing of wood chips in containers could be a problem for winter time transports. The moisture content is a crucial factor and it was concluded that moisture levels above 38% are likely to result in freezing issues and that moisture levels below 31% are not likely to result in such issues. It was also shown that anti-adherent paint can reduce these problems since it showed significant anti-adhesive properties on frozen wood chips. To achieve these results a vibrating shock had to be added which means that vibration is required to initiate a release.

Sammanfattning

En av mänsklighetens största utmaningar genom tiderna är att lösa den växande klimatkrisen, vilken är en konsekvens av vår omfattande förbränning av fossila bränslen. Om vi misslyckas med att vända den negativa trenden kan irreversibla skador uppstå, vilket kan få oöverblickbara konsekvenser i framtiden. Med dessa utmaningar i åtanke är energiomställningen från fossila bränslen till förnyelsebara energikällor en viktig förutsättning. Ett steg i rätt riktning är att använda biobränsle för energiutvinning, eftersom dessa inte bidrar till en ökning av växthusgaserna. Denna rapport har fokuserat på användbara teknologier som finns tillgängliga för intermodala transporter av sådana produkter, då transportbranschen står för en stor andel av de totala utsläppen av koldioxid.

Denna studie har visat att det finns många tillgängliga koncept för intermodala transporter av biobränslen. Några av dessa är utvecklade för rena bulktransporter medan andra kan användas för flera godstyper. Det som utmärker lastbärare som är avsedda för bulklaster med låg densitet, såsom flis, är att de normalt har en högre volymkapacitet än generella lastbärare. Problemet är att de kan bli svåra att använda i intermodala flöden eftersom de är optimerade för antingen väg eller järnväg. Mot bakgrund av dålig harmonisering utav maximal höjd och bredd för väg- och järnvägsinfrastrukturen finns det en risk att optimerade lastbärare blir icke-kompatibla i intermodala nätverk.

Företag inom biobränsletransporter har uttryckt att omlastning av biobränsle inte utgör något stort problem då detta kan utföras snabbt och kostnadseffektivt. En multimodal transport, där olika lastbärare används för väg- och järnvägstransporten, har stora fördelar avseende vikt- och volymutnyttjande. Med en sådan transportlösning är det möjligt att uppnå en högre optimeringsgrad eftersom volymen anpassas till respektive transportslag, vilket inte är möjligt i samma utsträckning för intermodala lösningar. Mot bakgrund av detta är det svårt att inte beteckna intermodala lastbärare som en kompromisslösning mellan olika intressen.

Eftersom det är svårt att ändra lastbärarens längd-, bredd-, och höjddimensioner utan att överskrida de tillåtna dimensionerna för väg- och järnvägstransporter så kan en lösning vara att införa längre vägfordon. Idag är 25,25 m fordon tillåtna för vägtransporter i Sverige, vilket motsvarar en lastbil med tre containrar. Om den tillåtna maxlängden ökar till 30 m, en fordonsdimension som just nu testas på svenska vägar, kan ytterligare en enhet lastas. I ett sådant koncept ökar den sammanlagda utnyttjandegraden samtidigt som bränsleeffektiviteten förbättras.

För enkel hantering bör lastbäraren vara av ”open top typ” där godset kan lastas uppifrån. Tömningen bör kunna göras antingen genom att rotera enheten upp och ned eller genom dörrar på en av sidorna.

Det har i praktiska tester visat sig att fastfrysning av flis kan vara ett problem vid transporter vintertid. Fukthalten är en kritisk faktor och det har konstaterats att fukthalter över 38% sannolikt ger upphov till fastfrysningsproblem medan fukthalter under 31% sannolikt inte ger upphov till sådana problem. Det har också visats att antihäftande färg kan minska problemen eftersom tydliga antihäftande egenskaper påvisades på frusen flis. För att uppnå dessa resultat krävdes en vibrationschock.

1 Introduction

This report has been produced by MariTerm AB as a part of the BIOSUN project, "Sustainable Intermodal Supply Systems for biofuel and bulk freight", led by the University of Gothenburg – School of Business, Economics and Law. Within this project, biofuels are referred to biomass originated from forest products.

The project aims to analyze and develop intermodal transportation solutions for biofuel and is expected to result in proposals about how these transport systems should be designed. Within this scope MariTerm has contributed with technical input regarding the cargo transport units used in these intermodal transport flows, which corresponds to phase 4.3 in the project description. The study has been financed by the Swedish Transport Administration through the Swedish Intermodal Research Centre, SIR-C.

1.1 Background

In a historical content biofuel resources have been highly utilized for energy extraction but due to the industrial development during the last century, biofuels have become less important as a primary energy source – to the benefit of fossil fuels.

Today, the forest industry is mainly focused on the extraction of raw materials for timber and paper products, which are refined from logs. These biomass products are often considering being too usable for pure energy production, even if the commodity of such is valued at a very low level. Wooden products have many application markets in different business fields and the priority of use can therefore not be questioned. Timber is heavily used for construction purposes, in furniture and for paper products, which are examples of products that can hardly be replaced by other types of materials. To burn high quality logs for energy extraction is therefore not a realistic solution to the emerging energy and climate crisis. However, timber which cannot be used in other markets may be well suited for chipping and energy extraction, which is the case also when the timber supply is greater than the actual demand.

In modern industries, especially paper mills, the production usually generates waste heat or other byproducts which can be used for energy purposes, such as heating. In other cases bark and wood chips may be natural byproducts from sawmill industries, which can be used for combustion in heating plants in order to serve a certain energy demand. What these industries have in common is that the energy extraction is a secondary benefit to the core business. However, there is no doubt that these subsidiary activities are beneficial for the climate and for the long term ambition of replacing fossil fuels with sustainable energy solutions in the future. This energy input is an important contribution to the support of the gradual transition to renewable energy sources, but it is not enough.

During felling activities trees are being cut near the stump in order to achieve as much timber material as possible. The top and tree branches are removed and the remaining log is placed on a log dump before it is picked up for transport. This is the normal procedure for extraction of trees for non-energy purposes. In a broader sense it is, however, important to highlight that this mindset is far from optimal since there is a lot of biomass left at the felling site after logging, biomass which is suitable for pure energy extraction due to the lack of other suitable applications. Tree branches, roots and tops are residuals that have the potential of being used for combustion in heating/power plants in order to produce renewable energy for the future.

A major reason why residual biomass is left behind when logging activities are completed is the cost sensitivity of such productions. In this perspective the costs for handling and transport are essential for the efficiency in this kind of exploitation. This report aims to focus on how to optimize the cargo transport unit for utilization in existing intermodal networks, both regarding handling possibilities and design opportunities.

1.2 Purpose and scope of phase 4.3

The aim of phase 4.3 is to find improvements for existing cargo transport units and associated handling equipment in order to facilitate loading, unloading and transshipment operations for intermodal transports of biofuel. These proposals shall aim to reduce the transportation costs for such transport networks.

The study is divided into the following four phases:

Phase 1 Focus on challenges and difficulties
Existing cargo transport units and associated handling equipment shall be identified through previous and ongoing research projects. Based on the knowledge achieved in this phase, a list of design requirements shall be made.

Phase 2 Analysis of challenges and difficulties
The list of design requirements developed in phase 1 shall be compared to existing CTUs such as containers, swap bodies, roll on roll off containers and trailers. Questions to be answered are: What are the advantages and disadvantages for each CTU concept? What is the reason for the disadvantages?

Phase 3 Develop solutions to identified challenges and difficulties
Based on the analysis in phase 2 the study aims to propose whether existing equipment should be improved or if new concepts should be developed.

Phase 4 Develop a proposal for a demo project
Based on the previous phases a demo project proposal shall be developed.

1.2.1 Methodology

One conclusion that can be made regarding available information about transport technologies for biofuels is the lack of independent data sources. There are few studies made in the field of intermodal transports of biofuel and relevant information for this study has been provided mainly by companies working with development of intermodal cargo transport units. Some of them have been willing to share non-official information but generally it has been difficult to get information which isn't available on the internet. Regarding manufacturing costs, prices and number of operators, none of the studied companies have shared any information. Based on these conditions, internet has been used as our primary source of information.

The information achieved on the internet has been analyzed and compiled to comparable data. Since it has been difficult to get information about some parameters like costs and prices, our main focus has been to use volume and weight capacities for different kinds of cargo transport units as our key indicators for comparison. We believe that the volume and weight capacities are the most relevant parameters in terms of transport efficiency, even though purchase prices and maintenance costs could differ slightly between different concepts.

As there is a great lack of available information regarding intermodal cargo transport technologies for biofuels, we believe that this report is an important contribution to further studies in the biofuel transport field. It should have a value for future studies which are intended to dig even further into other aspects, such as the economical perspective.

1.3 Expected results

This study aims to cover the transport technology aspects of biofuel shipments and to evaluate how these technologies can facilitate intermodal transports of biofuels. The results are intended to highlight potential improvements of intermodal cargo transport units that could be used in future supply chains of biofuels, from the felling site to the power or heating plant. In a general scope this aims to facilitate the transition to renewable energy sources, independent of fossil fuels.

2 General description of biofuel handling

Biofuels can be handled in different ways, either in processed or unprocessed conditions. What determines which handling technique to use is based on factors like transport distance between the production site and the energy plant, availability of processing equipment and the cost for processing and transport.

To some extent the utilization level during transport becomes more important with increased distance and since processed biomass allows less void spaces than unprocessed biomass - this method is preferred for longer transports. For shorter distances it could be cheaper to consider unprocessed biomass, which can be used only if processing facilities are available in the following supply chain downstream. However, when the biomass is ready for combustion in an energy plant, it has to be processed in some way. It is also very common that the plant has certain requirements on incoming products before energy extraction is to be considered, where size and moisture content are two important parameters for effective combustion.

2.1 Dismemberment of branches, roots and tops

Dismemberment is a technique used to decrease the volume of unprocessed branches, roots and tops, with the aim of attaining higher transport efficiency at a lower cost. Unprocessed branches, roots and tops are estimated to have about 20% biomass per volumetric unit, which should be compared to dismembered products where 40% biomass is achieved per volume.[1]

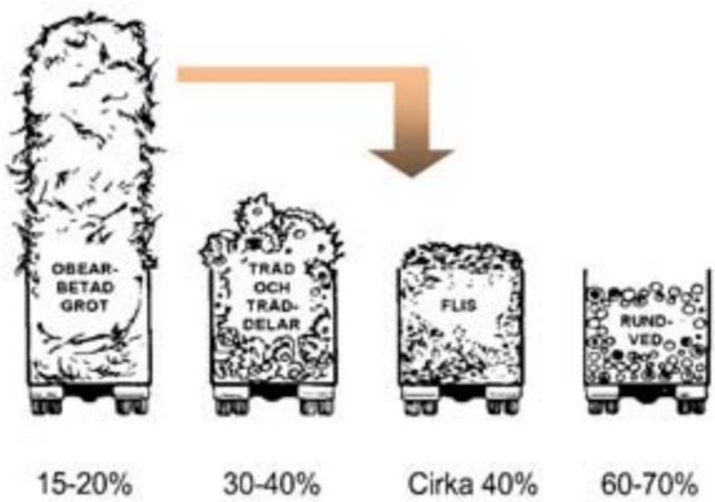


Figure 1 Biomass per volumetric unit for different kinds of processing levels (sönderdelning och transport)

Chipping and crushing are two commonly used methods for dismemberment and these activities could be executed on various places, based on the condi-

[1] Sönderdelning och transport – nycklar till effektivare skogsbränslesystem, s 27

tions given within a specific supply chain network. It could be done at the felling site, at a log dump or in a terminal, however, there is no general rule of thumb prescribing in which of these places dismemberment should be performed but for transport - early dismemberment may be a preferred option. In an overall perspective whatsoever, the cost for decentralized chipping/crushing has to be considered as these methods may be less cost efficient than centralized handling. For a certain production, balance should be achieved for both transport and handling costs, which then determines the suitable place of dismemberment.

2.1.1 Dismemberment at the felling site

At the felling site branches, roots and tops are spread over a wide area and normally these are picked up by a forwarder which transports them to a log dump for storage or further processing. In some cases, however, it may not be possible to provide enough biomass to engage the chipper continuously at the log dump, especially on smaller productions, and for such circumstances chipping may be undertaken directly at the felling site. The woodchips are then blown to an on board CTU in which they are stored during the transport to or from the log dump. When reaching the dump the chips are tipped over to the ground or directly to another CTU which should be used for the external transport.

Figure 2 Unloading of wood chips to a roll container (Skogen - en växande energikälla)

Chipping at the felling site is not a very common method of dismemberment of tree residues and a major reason for this is the additional costs which may arise for such activities. To combine the functions of a chipper with an ordinary forwarder is however a favorable solution since the terrain transport cost could be reduced. The disadvantage is that the chipper is passive during the transport work, both on inbound and outbound transports to or from the log dump. This is negative when it comes to the chipper's utilization level and since it is inactive for a considerable time - the cost for chipping increases. Based on this the demand of internal transports at the felling site should be carefully estimated before this solution is considered. Dismemberment at the felling site becomes less attractive in transport intensive productions and the field size is therefore of great importance.

Figure 3 Chipping at the felling site (Ljungstroms.com)

2.1.2 Dismemberment at a log dump

For most productions, dismemberment takes place at a log dump where tree residues are dropped off by the forwarders. This may be suitable when the utilization level of the chipper is crucial, which use to be the case on lager productions where process optimization is important. In such cases it may be possible to engage the chipper continuously by providing biomass from several forwarders.

There are two different approaches possible for dismemberment performed at a log dump, dependent and independent dismemberment. When an independent solution is used the chipper blows the woodchip directly onto the ground, which means that the chipper is active as long as there are residues to process. The woodchips are then picked up by an external transport vehicle equipped with a chip bucket, which enables a separation between the chipping and loading activities in a way which reduces the risk of passivity. This presupposes that the chip stack can be reached from a nearby road since the external vehicles usually don't have the ability to transport in terrains. This may be a disadvantage since the chip stack cannot be spread too far from the road.

Figure 4 Chipping directly to the ground (Skogen - en växande energikälla)

In the dependent solution the woodchips are blown directly to a suitable cargo transport unit without passing the ground. In a perfect world this is a superior method since it allows a reduction of the handling costs, however, the reality is far more complex. The disadvantage with the dependent solution is that it requires a well-coordinated schedule between the chipper and the incoming CTUs. If a CTU is missed when another is being picked up, the chipper becomes passive. On the other side, the utilization level of the CTUs may become insufficient if they are supplied too early. A well-coordinated schedule between the chipper and the external transports is essential for an efficient production based on the dependent method. In general it is however preferable to attain higher utilization level for the chipper than for the CTUs, since the active handling costs are much more crucial than the passive asset costs for the CTUs.

Figure 5 Chipping directly into a CTU (Skogen - en växande energikälla)

2.1.3 Dismemberment at a terminal

The dismemberment costs could be a major part of the overall handling costs, which may increase in decentralized arrangements where the risks of passivity is higher due to the lack of available residues. One way of dealing with this might be chipping performed with stationary equipment in an external facility. The advantage is that tree residues are aggregated from many different locations, which most probably increases the chipping quantity to levels where the chipper has better potential of being utilized more frequently.

Figure 6 Chipping at a terminal (Skogen - en växande energikälla)

When dismemberment is executed in a terminal the transport costs, transport distance and utilization level during transport are all of great importance. In general, centralized chipping is not a suitable method when the transport distance between the terminal and the logging site becomes too large, which is closely linked to the carried quantity and the transport cost. Unchipped residues are much more voluminous than chipped residues which have a big impact on the ability to use stationary chippers in a terminal. Based on this the transport distance is crucial, mainly because it results in higher transport costs than equal transports with chipped quantities. To increase the utilization level of the CTUs, methods have been developed in order to create compression – which aims to get less volume per carried biomass quantity.

An advantage with unchipped biomass is that it is far more capable of being stored for longer periods than dismembered biomass, due to the risk of biological degradation.

2.1.3.1 Unprocessed biomass – branches, roots and tops

The easiest method to distribute tree residues from the forest to a chipping facility is to load it onto a road vehicle in an unprocessed condition. This can be done fast and effective with less equipment required at the production site, the loading procedure is usually carried out by a loading grapple placed directly onto the road vehicle – which is handled by the driver. However, the unprocessed biomass is quite voluminous and therefore it could be difficult to achieve a utilization level high enough to make it profitable. In order to minimize the void space compression is commonly created by the loading grapple, which is done when the residues are placed in the CTU. Studies performed by SkogForsk during the early 1990's have shown that such compression results in a 27-35 percent increase of the carried biomass quantity.[2] However, the cargo weight achieved through compression is approximately 22 tons and compared to the maximum allowed cargo weight of 26 – 30 tons, there is still potential for further improvements.

Figure 7 Unprocessed biomass (Skogen - en växande energikälla)

If the road transport vehicle isn't equipped with an own loading grapple, this may allow larger quantities due to the possibility of bigger CTUs. On the other hand this would require a specific loading vehicle at the log dump, which could be difficult to employ continuously due to the uncertain availability of CTUs.

2.1.3.2 Processed biomass –bundling of branches, roots and tops

If centralized chipping is considered being the most appropriate solution for a specific production, but the transport costs for unprocessed biomass are too high, processed biomass might be a suitable option.

Bundling is a form of processing that aims to reduce the biomass volume through compression, without cutting the residues into smaller pieces. This is done by vehicles equipped with a bundler and in most cases this use to be the forwarder, however - similar equipment may be found on a modified truck even though it is less common. There are a lot of advantages associated with bundling at the felling site compared to bundling at the log dump, especially when it comes to the cost for transport between these two locations – which is necessary in both cases. If bundling is done at the felling site the forwarder has a greater ability to attain higher utilization level during transport than for transports with unbundled residues. If bundling has to be done in any stage during the process, it is probably difficult to find motives for bundling which takes place in a later phase than during the forwarding operation.

[2] System för hantering av GROT, s 23

Figure 8 Processed biomass, bundling of branches, roots and tops (Bioenergi från skogen 2003-2007)

One of the main reasons why bundled biomass became interesting, except from the ambition to increase the utilization level of the CTU, was the possibility to use existing timber log trailers for these types of transports. The stanchions on a log trailer are placed up to several meters apart and due to the non-rigid properties for unprocessed residues, transports of such wouldn't be possible. However, when the biomass is bundled into larger units, they can be loaded onto the log trailer in a similar way as timber logs, where support is achieved in the transverse direction through the stanchions.

During demo projects it has been shown that bundling may not be fully sufficient regarding the ability to keep single branches or particles within the bundle. The speed related air draft creates turbulence that releases considerable amounts of dust behind the vehicle during transport, which is a big issue. Due to this, transports of bundled biomass in existing log trailers are not commercially operational as of today, but tests have been done with windshields attached to the sides, which probably reduce the turbulence to some extent. Another problem which cannot be solved by this technique is the felling risk of larger branches, roots and tops, which may be the case if the bundles are bursting during transport. In such cases the pressure could be high enough to press the windshield outwards, which may result in a release of larger quantities onto the road.

Figure 9 Transport of bundled residues (Vidaretransport av skogsenergisortiment)

2.2 Description of distribution patterns for dismembered and non-dismembered tree residues

Even though it is not possible to determine general procedures for dismemberment activities, some residues are more common than others in different types of supply chain networks. Despite the technical aspect of dismemberment, the logistical layout is essential for a successful distribution of biofuels.

For ordinary distribution patterns, based on unprocessed, bundled and chipped residues, the supply chain cost can be divided into three major items – consolidating, processing and transport. Since the market value for tree residues is quite low it is important to continuously optimize the supply chain in order to increase the margins and thereto make the business more profitable. For such optimization processes the "economy of scale" concept may be a suitable tool to utilize, but in some cases it is necessary to deviate from such recommendations since other options could be more favorable.

In dense communities it is likely that the transport distance between the production site and the heating/power plant is lesser than in scattered regions. Energy plants are often located in highly populated areas where the energy demand is high, but on the contrary, large forest areas are commonly found in sparsely populated regions. In Sweden, Norrland has huge reserves of biomass due to an extensive forest landscape, but at the same time, most heating plants are located in the southern parts of the country. To meet this demand is a logistical challenge for the industry and due to small economical margins the business becomes tough. For this reason it is necessary to offer different types of supply chain networks, based on the provisions valid for a certain production field.

Transports of tree residues intended for energy extraction are a bit odd in comparison to ordinary transports of goods, since the cost factor is more crucial due to the low cargo value. The sensitivity for additional costs is therefore much higher for these transports than for transports where the cost has a lesser share of the total cargo value.

There are two major principles suitable for the distribution of tree residues from the production site to the heating/power plant. The first one is considered to be the simplest one, a direct transport where a vehicle picks up the residue at the log dump and then transport it to the plant without any interruptions or transshipments in-between. The other option would be to split the transport chain into two separate links connected through a terminal operation, which requires a lot more planning and coordination between the involved parties in order to minimize the risk of delays or bad levels of utilization.

Figure 10 Example of a non-intermodal transport

Figure 11 Example of an Intermodal/multimodal transport

2.2.1 Direct transports

In general, direct transports by road are commonly used for regional transports of goods and a major reason for this could be the price level relative to the expected time of delivery. It uses to be the fastest way of shipping, except from air transports, for a cost not much higher than for intermodal alternatives. Direct transports are easy to use since they have a great level of flexibility and at the same time low requirements on planning, which are valuable aspects for an industry operating in a volatile world. Direct transports are usually only suitable for cargo volumes which include full CTU loads, since broken volumes and general cargoes have to be transshipped in most cases in order to reach the end consumer through diverging transport links. For direct transports, the shipper and the receiver are connected through one single link, operated by one vehicle. This reduces the risk of external impact that could decrease the transport quality level.

2.2.1.1 Direct transports of unprocessed residues

Unprocessed residues are quite voluminous due to the fact that they create void space within the CTU which are difficult to eliminate without some sort of dismemberment. This is an important aspect to consider when a suitable transport option is to be selected, since unprocessed residues could be very costly during some circumstances.

Figure 12 Transport of unprocessed residues (Vidaretransport av skogsenergisortiment)

Direct transports of unprocessed residues are usually not suitable for longer transports since the distance based cost eventually eliminates the total value of the cargo. The distance where such a break point occurs depends, among others, on the utilization level of the CTU. Unprocessed residues in direct transports are therefore more sensitive for high transport distances than other levels of processed residues like bundled and chipped biomass products. During the last steps of the supply chain, the unprocessed material is intended to be dismembered at the receiving industry since it is delivered completely unprepared for the final combustion. This could result in lower chipping costs since a higher input of biomass in combination with a more efficient chipper leads to the economy of scale.

2.2.1.2 Direct transport of bundled residues

If unprocessed residues are considered being too costly for direct transports, bundled residues may be a suitable alternative. The bundling cost is comparably low in relation to the positive cost effects achieved by an increased cargo quantity for transport. With more cargo carried during transport it is also possible to admit longer transports, since the cargo value increases as well. This leads to a lower cost sensitivity compared to unprocessed residues, which is beneficial for the overall productivity.

Bundled residues are still more voluminous than chipped residues and this is the reason why bundled residues are unfavorable for longer transports, for which dismembered residues could be better suited. However, based on the low bundling costs it could be suitable to incorporate bundles also for short transports, if the transport income increases more than the additional costs for bundling. However, it is important to highlight that costs may be added also for dismantling of bundles at the place of reception, since most chippers aren't capable of processing bundles with a diameter of 70 cm or higher.[3] This may be the case due to small intake valves or due to restrictions in engine power.

2.2.1.3 Direct transport of chipped residues

Chipping of tree residues is highly recommended for direct transports in cases where the receiving industry is located at intermediate or long distances away from the production site. This is the most convenient method for such distribution networks, since it could be difficult to achieve a sufficient level of utilization without having the residues chipped before transport. However, this is a method which consequently leads to higher chipping costs, but which could easily be refunded through the more efficient transport. Chipping of tree residues at the production site is yet increasing the risk of passivity due to lacking supply flows, which could be the case when the internal transport distances are large or if the production site is too small relative to the capacity of the chipper.

Direct transports of chipped residues could preferably be done with high capacity vehicles, like biomass trailers, since these usually admit higher volumes than for example containers. The capacity of these biomass trailers could vary between different concepts but in most cases it is possible to achieve cargo volumes of up to 140 m^3, which is equal to approximately 37 tons of residues.[4] For vehicles equipped with a chip bucket the cargo capacity is usually lesser than for vehicles which are loaded by an external unit.

[3] Systemanalys av skogsbränsletransporter, s 12
[4] De olika systemen för sönderdelning och transport ställer olika krav

Figure 13 Transport of chipped residues by road (Nytt fordon för transport av bränsleflis)

Since chipped residues are more sensitive for storage, due to the microbial activity that starts when wood chips are placed in stacks on the ground, direct transports have to be well coordinated in order to maintain the biomass pretty intact. In other words, direct transports are inconvenient for supply chains where there is a gap between the reception of the biomass and the final combustion in the energy plant. For such deliveries bundled tree residues could be preferable also for transport distances which are not economically optimal, but for which it is possible to get higher energy output in the final combustion due to better storage properties.

2.2.2 Transport via terminal

In some cases direct transports are not optimal for the distribution of tree residues. The most common reason for this might be the aim of getting the residues through a terminal in order to get it chipped, which uses to be more efficient than decentralized chipping. Even though there are some economic advantages related to a centralized chipping activity, the additional costs associated with the transshipment are important to highlight since they could be significant due to the low cargo value.

Figure 14 Loading of wood chips in a terminal (stinsensforum.se)

The “hub and spoke” theory is the concept by which terminals are incorporated between diverging transport links in order to create better services to the customers. By using terminals it is possible to link different transport routes together which then enables more destinations from a single location. This is a great advantage for shipping orders which do not fill an entire cargo transport unit or a full train set, which otherwise would be very expensive to distribute in a direct transport flow. One of the main purposes with transshipment terminals is therefore to consolidate small volumes into larger volumes, which increases the transport efficiency and thereby decreases the cost and environmental impacts. With this said, transshipment terminals are beneficial in many ways but nevertheless, disadvantages like time consumption and transshipment related risks like cargo damage are always present.

Due to additional activities that arise when goods are to be distributed in a hub and spoke network, the transport time could be affected negatively. In most cases it is necessary to have time margins between incoming goods and outgoing goods to and from the terminal, both in cases of unexpected delays but also for the aggregation process which includes time for storage during the collection of goods coming from different locations. In a general view it is therefore reasonable to assume that transports through terminals are more time consuming than direct transports. This is however an explanation filled with limitations and one exception from this could be when the main transport is longer than what can be reached within the time limits set for the driver, before the required time of rest is activated. In these cases it is not unrealistic that hub and spoke transports offer quicker deliveries compared to direct transports.

<table>
<tr><td></td><td></td><td colspan="3">Level of processing</td></tr>
<tr><td></td><td></td><td>Unprocessed residues</td><td>Bundled residues</td><td>Chipped residues</td></tr>
<tr><td rowspan="6">Distribution patterns</td><td>Direct transport</td><td></td><td></td><td></td></tr>
<tr><td>Forest to heating/power plant</td><td>Suitable for short distances</td><td>Suitable for short to intermediate distances</td><td>Suitable for intermediate to long distances</td></tr>
<tr><td>Transport via terminal</td><td></td><td></td><td></td></tr>
<tr><td>Forest to terminal</td><td>Suitable for chipping at terminal</td><td>Suitable for chipping at terminal</td><td>Suitable for long distances via intermodal transports</td></tr>
<tr><td>Terminal to heat-ing/power plant</td><td>Unfavorable if unchipped</td><td>Suitable for chipped resi-dues</td><td>Suitable for long distances via intermodal transports</td></tr>
</table>

Table 1 Transport suitability for different levels of processing

3 Technical restrictions in different modes of transport

One of the major issues related to intermodal transports of goods is the technical restrictions that characterize different modes of transport. Minor changes in width or height of a vehicle or a cargo transport unit could make it incompatible with intermodal transport chains. In order to reduce the risk of such incompatibility, the unit may be designed with dimensions which do not utilize the whole volume available within a certain transport mode. In comparison with combined transports, where goods are reloaded between two or more transport modes, the transport efficiency may decrease due to smaller utilization levels during transports with undersized capacity units.

Another type of restriction which may affect the utilization level is differences in allowable weight. If a unit is allowed to have a higher weight on a railway wagon compared to a road trailer, the unit will not be ideal for intermodal railway transports.

Transports which exceed the technical restrictions are to be considered as “unauthorized” and a certain exemption is then required by the responsible transport administration. These transports cannot be performed without such approval.

3.1 Loading gauges

Loading gauges are probably one of the most important parameters to determine whether a unit is compatible or incompatible for transports within a certain transport network. The profile layout is usually given with maximum width and height, which are used to define the maximum allowed dimensions found in the widest/highest cross-section of the vehicle or cargo transport unit. For road vehicles, the profile is usually restricted by bridges and current width of the road. Railway wagons are normally dimensioned based on standard dimensions used in tunnel constructions.

The loading gauges could vary not only between different transport modes but also within specific transport modes. This is the case for the Swedish railway, where three different types of railway classes have been established. This could be problematic for intermodal transports since it diminishes the potential of high utilization in the railway network.

Another issue related to loading gauges is diverging standards between different countries. For domestic transports this would normally not cause any problems, but for intermodal transports in international traffic the barriers could be greater.

The loading gauge has a great impact on transports of goods loaded by volume, since an increased dimension automatically enables larger transport quantities.

3.1.1 Road transports

The loading gauge for road transports is restricted in width and height by the national legislation. The maximum length is also an important factor for road transports since it decides how cargo transport units can be combined within the length restrictions.

3.1.1.1 Width

The maximum height and width dimensions for road transports within the European Union are well harmonized and only a few exemptions are made by some countries. The standard width for these transports is 2.55 m but for vehicles with controlled temperatures a width of 2.60 m could be allowed due to thicker walls for isolation purposes. Even though the maximum width is more or less the same within the Union, its legal status is nationally determined by the Swedish Transport Agency (Transportstyrelsen).

There is an additional rule applicable for transports with inseparable cargo on Swedish roads, for which a maximum width of 3.1 m could be acceptable without a certain exemption by the authority. Such cargo shall be marked with suitable signs in red and yellow colors, placed at the extreme ends of the unit. It shall also be marked with the text “Bred last” in order to be properly fitted for such transports. On the other hand, the characteristics of an “inseparable cargo” are not perfectly defined and there is a lot of room for personal assumptions. According to a phone call with a representative for the Swedish Transport Agency, it is up to the legal government to establish a statement on how the regulation should be interpreted. It is therefore not clear if a container, swap-body or roll-off container can fall under this exemption rule or not, which could explain why some non-tempered cargo transport units are available for a width of 2.60 m.[5] Another explanation could be that these units have to apply for governmental exemptions.

For temperature controlled vehicles **2.60 m** | For non-tempered vehicles **2.55 m**

Figure 15 Maximum width on swedish roads (Trafikverket)

[5] For example, see ”CMT OptiCont FlisMax

3.1.1.2 Height

The maximum standard height for road vehicles within the European Union is 4 m, but some countries have decided not to define a maximum allowed height – for example Sweden, France, Norway and the United Kingdom. It is uncertain why these countries do not have any height restrictions for road transports, especially since bridges, tunnels etc. are built for specific dimensions. In Sweden, however, new road constructions are built for a minimum free height of 4.50 m and constructions lower than that have to be marked with a signboard showing the actual free height. For that reason, a maximum standard height for Swedish road vehicles would be estimated to 4.50 m, even though legal restrictions are lacking.

Figure 16 Collision with a bridge due to height restriction (sverigesradio.se)

3.1.1.3 Length

In addition to the height and width restrictions, road vehicles have to fit into a longitudinal dimension, which varies between different countries. For road transports within the European Union, most cargo transport units are standardized with dimensions which are equal to the size of swap-bodies and semitrailers. These dimensions are included in a concept called "The European Modular System", which has been established in order to allow existing modules to be combined into longer and sometimes heavier transport units. These EMS setups are not allowed for transports in all member states but in Sweden, Finland, Norway, Denmark and the Netherlands, road trains with a maximum length of 25.25 m are allowed. This should be compared to other parts of EU where the maximum length is limited to 18.75 m for road trains. In the Nordic countries as well as the Netherlands it is therefore possible to combine a swap-body and a tractor with semitrailer but in other countries only two swap-bodies can be combined with one tractor, filling up the maximum 18.75 m in length.

Both 20' and 40' containers fit into the semitrailer and swap-body dimensions but if 45' containers are to be carried on trailer chassis - these units need to be exempted in the national legislation. The reason for this is that 45' containers are 11 centimeters longer than the maximum length of a semitrailer module, which means they overhang the trailer in the longitudinal direction.

Figure 17 A 45 ft. container loaded onto a semitrailer chassis (cargobull.com)

A semitrailer is built for a maximum length of 13.6 m and swap-bodies for a maximum length of 7.82 m. Based on the current legislation, these units can be combined in the following ways.

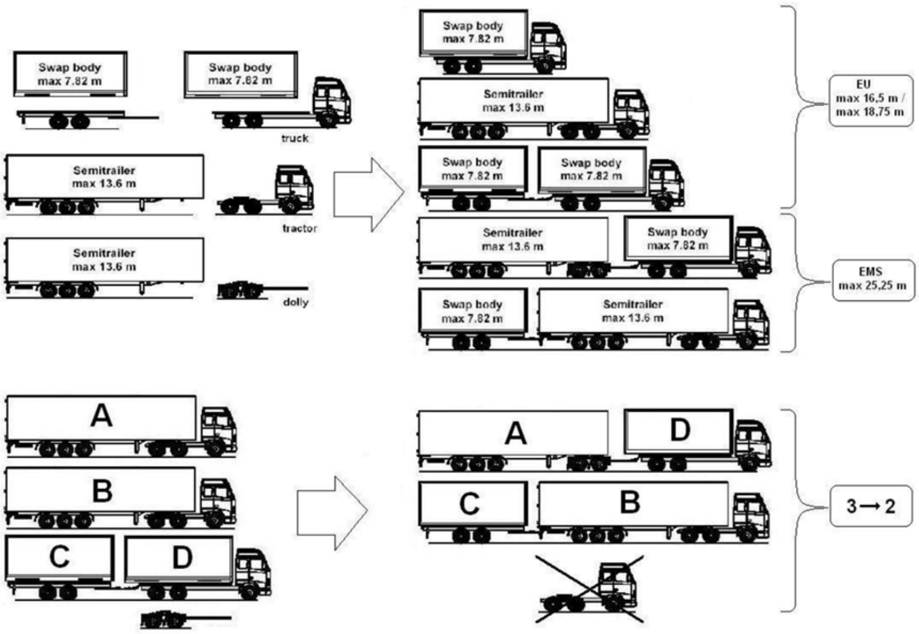


Figure 18 Illustration of the European Modular System (Tfk 2007:2 E)

3.1.1.4 Effects of the European Modular System

The European Modular System enables a variety of different vehicle combinations, which is beneficial for the flexibility and transport efficiency - when applicable. The standard dimensions of these modular units have developed over time but it is unlikely that these will change significantly in a short and mid-term perspective. It is more likely that countries will extend the legal and technical applicability of these units within their own nations, which could have positive effects in both economic and non-economic issues.

One of the most beneficial factors with longer and heavier module vehicles is the environmental advantages, which follows when more goods could be carried by fewer trucks. That means less fuel consumption per cargo transport unit, more efficient transports, less congestion, increased road safety and reduced total costs. It is also likely that flexible vehicle combinations facilitate intermodal transports, as the cargo transport units can be combined in a way where maximum efficiency is achieved for a specific transport route, which could be difficult with fewer options. The disadvantages with longer and heavier vehicles is that the market share for road transports may increase, which is negative in an overall perspective since benefits from other transport modes could be lost. In addition to that, it is possible that modifications have to be made in existing infrastructure in order to allow longer and heavier vehicles, which could lead to high investment costs for the society as well as higher taxes and/or higher fees for road users.

The following table illustrates the advantages and disadvantages identified for the European Modular System, seen in an extended view.

Area	Most positive	Most negative	Result
Environment	Less fuel consumption per transported cargo unit.	May increase the market share of road transports	+
Economy, micro level	Reduced transports costs	Increased fuel consumption and maintenance per vehicle	+
Economy, macro level	More efficient transports, lower total costs	May need infrastructural adjustment	+
Congestion	Fewer vehicles transporting the same amount of goods	May increase the market share of road transports	+/-
Traffic safety	Fewer vehicles transporting the same amount of goods	Characteristics of the vehicles may increase the accident rate	+/-
Consequences on other transport modes	Facilitates intermodal transports	May increase the market share of road transports	+/-

Table 2 Effects of larger and heavier road vehicles based on the European Modular System (TfK report 2007:2 E)

Based on the positive effects associated with the European Modular System, it would probably not be beneficial to develop future cargo transport units with dimensions which fit badly into the modular concept. Such deviations could result in difficulties when it comes to transport efficiency and economic considerations. This would be even more important for low-valued cargo such as biomass products, as these could be heavily affected through bad utilization levels - due to low market prices.

3.1.2 Railway transports

The loading gauge for railway transports is based on two parameters, static and dynamic loading gauges. The static loading gauge is used to establish the maximum dimensions of a railway wagon which is placed on a straight track, while the dynamic gauge is increased by the distance added by overhanging parts of the wagon in curves as well as additional space followed by rolling or damages shock absorbers. If the railway wagon or cargo transport unit does not exceed these limits, the unit can be safely transported within the transport network, without the risk of colliding with other trains or fixed equipment.

In Sweden, three types of loading gauges are used for different parts of the railway network. These gauges can be divided into the following classes:

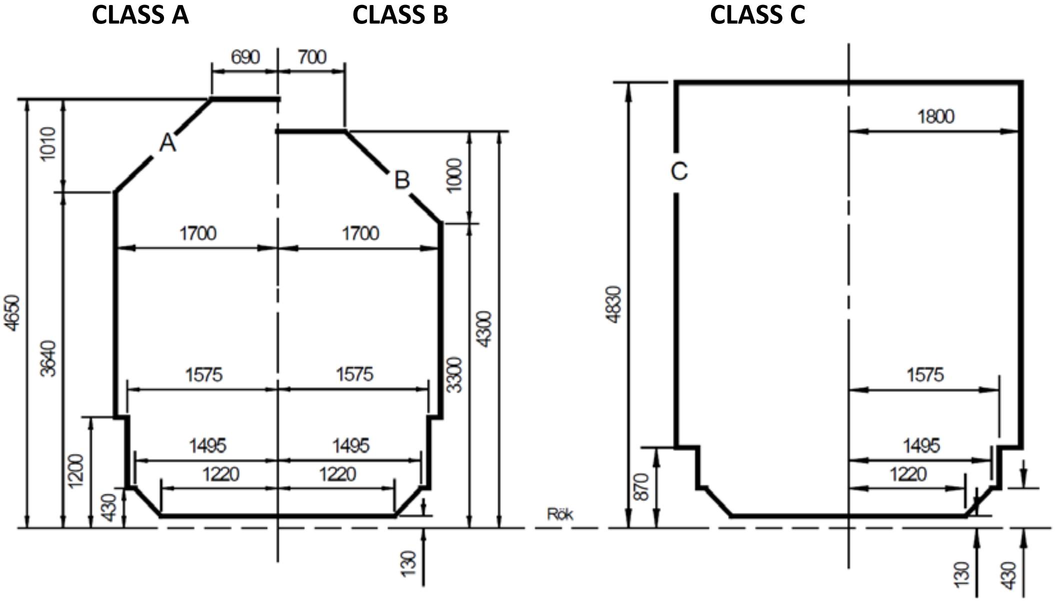


Figure 19 Loading gauges in Sweden (Trafikverket 2013)

3.1.2.1 Class A & B railways

Class A has been the standard loading gauge in Sweden for a long time. Railway tracks in this class have a width of 3.40 meter and a height of 4.65 meter, where the maximum height is located on top of the wagon - with decreasing height towards the sides. Wagons based on these dimensions are allowed to operate within the whole railway network, except from the transport route Kiruna – Riksgränsen - where class B is required.

Class B is equal to class A in width but has a lower maximum height of 4.30 meter. Class B does not fulfill the requirements in the European loading gauges GA and GB.

The disadvantage with loading gauges A and B is that they could be difficult to load efficiently due to the tapered roof. The reason why this form has been chosen is because older bridges have tapered sides in their valves.

The extension of class A & B railways in Sweden is illustrated in the following picture:

Figure 20 Loading gauge class A & B in the Swedish railway network (TfK 2007)

3.1.2.2 Class C railways

The Swedish Transport Administration (Trafikverket) is working on the implementation of a larger loading gauge called class C. Railway tracks in this class have a width of 3.60 meter and a height of 4.83 meter, with no tapered sides towards the top of the roof. Compared to class A & B, class C has squared corners on the upper edges which increase the volume capacity by 25% in comparison to class A. This is a major advantage when it comes to the transport efficiency, since more goods can be carried into each cargo transport unit.

Class C tracks are not only implemented on new railway constructions but are also implemented on existing infrastructure. It has been shown that the costs for upgrading existing tracks to class C are relatively low in comparison to the annual investments made by the Swedish Transport Administration. For that reason there are a lot of advantages associated with further investments in larger loading gauges.

For continental transports the Öresund bridge has been built in accordance with loading gauge C and there are indicators saying that the upcoming Fehrman Belt tunnel will be built with equal dimensions. There are also plans of increasing the loading gauges in central Europe, including Germany, which corresponds to the European ambition of achieving better integration and harmonization between standards in different member states.

The extension of class C railways in Sweden is illustrated in the following picture:

Figure 21 Loading gauge class C in the Swedish railway network (Banverket 2006)

3.1.2.3 European standards

For international railway transports within the European Union, the European loading gauge GA could be used for most railway networks, except from transports performed in Great Britain. Tracks based on this loading gauge have a width of 3.15 meter and a height of 4.32 meter, where the maximum height is located on top of the wagon - with decreasing height towards the sides. However, railways in central Europe are built in accordance with loading gauge GC, which has a width of 3.15 meter and a height of 4.65 meter. As for the European loading gauge GA, the maximum height is located on top of the wagon - with decreasing height towards the sides. All member states within the European Union are required to construct new railways in accordance with the GC gauge or larger.

As can be seen in the illustration below, a standard ISO container as well as a high cube container fit into all loading gauges when stowed on a standard flat deck wagon with a free maximum height of 940 mm.

The European loading gauges GA and GB fit into the Swedish “class A” while loading gauge GC fit into “class C”.

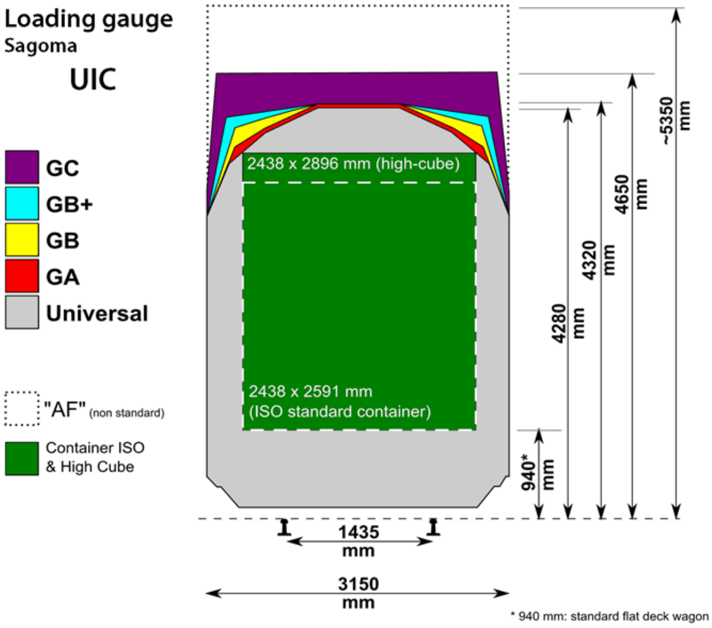


Figure 22 European loading gauges (Cheminvento)

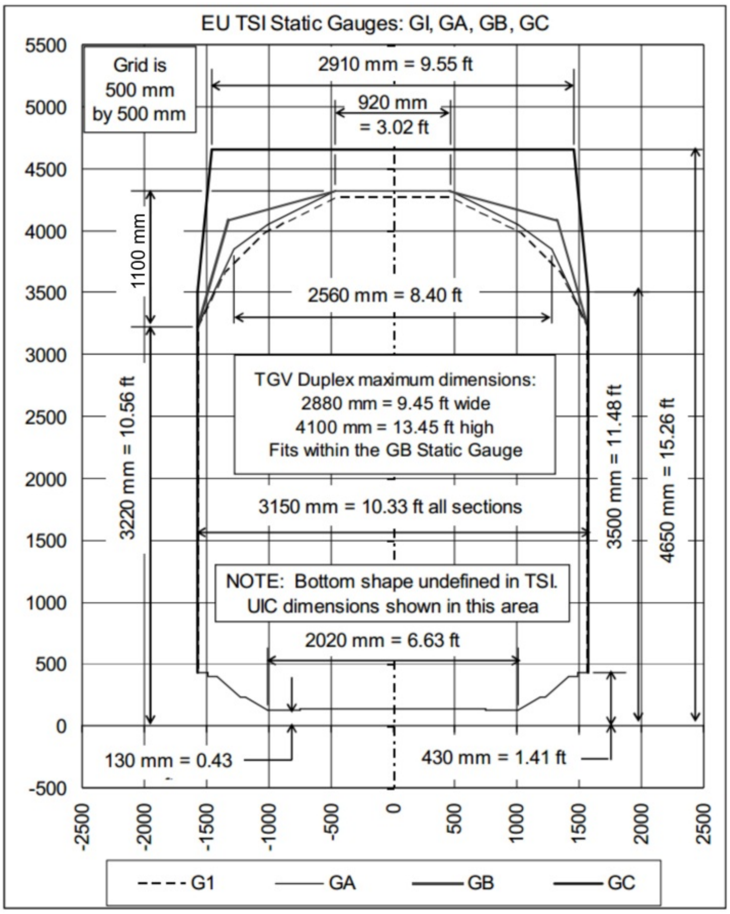


Figure 23 Dimensions for European loading gauges "G1", "GA", "GB", "GC" (California High-Speed Train Project)

3.2 Common carriers

When new intermodal transport chains are to be developed, a review of existing infrastructure is essential for a successful transition. Even if a completely new transport system would be preferable based on the unique properties of the cargo, a new system will normally give rise to major disadvantages and barriers which have to be mastered before high efficiency can be achieved. The costs for implementing new transport structures could be very high and in many cases the project may end up in stagnation and failure. In other words, the risks associated with over-ambitious visions and actions may lead to an unsuccessful outcome, ultimately without adoption of the system.

If a new transport concept can be used in existing infrastructure and at the same time add new features to the system, there are a lot of advantages to benefit from. What an existing infrastructure can offer to new transport concepts is good availability and short start-up times. When cargo transport vehicles and fixed infrastructure are easy to access, the system could also benefit from lower initial costs. If a cargo transport unit is customized for compatibility with existing transport vehicles, the costs for positioning of empty carriers is one cost item that could be reduced due to higher supply and better coverage. With dedicated cargo transport units, where compatibility is achieved only by a small number of carriers, the costs for positioning would most probably be greater.

3.2.1 Road vehicles

Road vehicles can be divided into two different categories, vehicles with an onboard CTU and vehicles for external CTUs. Vehicles with a built-in CTU have to be transported in an unseparated condition during intermodal transports, as the cargo transport unit cannot be unloaded from the chassis. The most common vehicle in this category is probably the box semitrailer, which can be used in intermodal transport chains at sea and on rail, provided the unit is equipped for such transports. The disadvantage with these units in an intermodal perspective is that the chassis has to be handled during transshipment and transport, which may decrease the overall efficiency.

Road vehicles intended for external CTUs are equipped with devices which are customized for certain types of cargo transport units. Some vehicles may be able to handled different kinds of CTUs, but usually they are designed for one specific CTU only.

This section will focus on road vehicles for external CTUs, as these units facilitate the intermodal transport chain without being an immediate part of it.

3.2.1.1 Hook lift truck & trailers for roll-off containers

The hook lift system is a concept built for easy loading and unloading of roll-off containers. The system was invented during the late 1940’s and is today considered to be one of the major transport solutions used on the market.

The roll-off concept is however not suitable for all kinds of transports, like an ordinary ISO container, which is a direct consequence of the unique loading and unloading properties.

Loading technique

The loading and unloading procedures are based on a technique where the roll-off container is tilted in the longitudinal direction. This is the essence of the construction which allows the roll-off container to overcome the height difference between the trailer and the ground level, without being lifted from above. This is the most important factor why the roll-off technique isn't suitable for all kinds of goods, especially not for general cargo.

The truck is equipped with a hook which can be moved both in the longitudinal and vertical directions. By placing the truck right in front of the roll-off container, which is placed in the longitudinal direction as well, the hook grabs the container and starts tipping it upwards and forward. Before the center of the container has reached the back of the trailer chassis, it slips on the wheels mounted on the rear end of the container. When the center has been reached, the container is leveled over the trailer edge and is then pulled forward until it is fully positioned on the chassis. During this maneuver the container slips over wheels on the rear edge of the trailer and full length contact between container and trailer is achieved first when the container is in position at the front.

Figure 24 Hook lift truck for roll-off container handling (palfinger.com)

The hook lift system is applicable not only for single truck vehicles but also for trucks with associated trailers, either for one or two 20 ft. roll-off containers. The latter option is common for transports on Swedish roads as this vehicle combination can utilize the maximum length of 25.25 m, using one truck and one semitrailer. When roll-off containers shall be loaded onto a semitrailer, they must be picked up in the same way as if they would be transported on the truck. When the first container is picked up, the truck is placed in front of the semitrailer and the hook pushes the container backwards until it is in position. Then, the truck picks up the second container and repeats the procedure once again. When both containers are loaded on the semitrailer, the last container can be loaded on the truck, filling up the whole road train. The loading procedure for a truck with trailer is illustrated below.

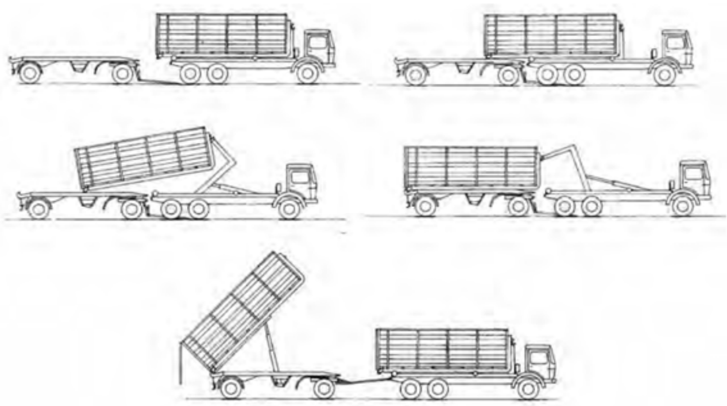


Figure 25 Loading of roll-off containers (Woxenius 1998)

In contrast to the truck chassis, the trailer chassis could be fitted with two tracks on which the roll container can slide, both with the same width as the wheels located on the rear end of the container. If these tracks are lacking, the chassis must have a central track where the framework of the roll container can slide. The chassis must also be fitted with a suitable locking arrangement, which grabs around attachment points built into the bottom of the container. With these requirements, it is not possible to transport roll containers on standard chassis. An example of a compatible chassis is illustrated below.

Figure 26 Trailer for roll-off containers (Schwarzmueller.com/cmt.se)

Application markets
In a handling and capacity perspective, the roll-off container concept is highly suitable for different types of bulk cargoes, such as biofuels, waste and scrap. The volume capacity is generally higher in comparison to a standard container and a major advantage is that it can be modified in height, length and width in order to suite a certain demand, without affecting the handling possibilities. These units are usually filled from above and emptied through the rear doors during tilting, which make them very effective.

Figure 27 Truck and trailer with roll-off containers (Schwarzmueller.com/cmt.se)

Disadvantages
Since the weight of the unit is concentrated to a small area at the rear end during loading and unloading, the handling operation could be problematic if the ground is too soft. This could be the case during handling in the terrain and especially during raining periods where the ground may become muddy. Under these conditions, it is possible that the rear end of the roll container sinks into the ground and that the horizontal pulling force helps it to dig even further. One way of dealing with this problem could be not to unload the unit in the terrain, but have it stowed on the chassis during filling. This will, however, affect the utilization level of the chassis in a negative way.

3.2.1.2 Container chassis

Container chassis are used for container transports on road, which use to be intermodal since direct transports are not very common for containers. The design of the chassis may vary between different manufacturers but these can generally be divided into any of the following two categories; gooseneck or straight chassis.

Gooseneck chassis
The height of the chassis has a big impact on the volume capacity, since most countries have height restrictions for road vehicles. If the height of the chassis could be decreased, more space could be utilized for the container. One way of doing this is to reduce the size of the wheels, but that has to be made

also for the truck, otherwise it wouldn't have an effect. If the wheels on the truck are not reduced in size, the front part of the chassis will have the same height as before, which wouldn't be compatible with higher containers. The problem is that the chassis and the truck are two separate transport vehicles and the chassis has to be compatible with most trucks, not only modified trucks with wheels of reduced sizes. For that reason, the chassis has to be constructed with an alternative design in order to allow higher containers. These units are called gooseneck chassis since the front part is raised above the rest of the chassis, like a gooseneck. With this design, 40 ft. high cube containers can be transported without breaking the road regulations. That's possible since most 40 ft. containers have a tunnel in the front part, below the floor, which fits into the gooseneck structure.

Figure 28 Gooseneck container chassis (cargobull.com)

Straight chassis

Straight container chassis, without a gooseneck, have a flat loading surface which in most cases is located higher than the lowered part on a gooseneck chassis, measured from the ground level. With a maximum allowed height of 4 m for road vehicles, these chassis would be sufficient for transports of standard containers with a height of 2.59 m. However, for chassis with a standard height of 1.3 m the theoretical maximum height of the container would be 2.7 m.

Figure 29 Straight container chassis (cargobull.com)

Loading patterns

A semitrailer container chassis with a length of 13.6 m use to have different loading options for increased flexibility. The loading options are based on the 20 ft. and 40 ft. dimensions which mean that two 20 ft. containers can be loaded simultaneously, alternatively one 40 ft. container. This is determined by the twistlock locations on the chassis, which would allow 45 ft. containers as well, provided the twistlock corners are located at the same places as on a 40 ft. container. However, semitrailer container chassis are not compatible with double C-class swap-bodies even though they are fitted with twistlock corners in the same positions as a 20 ft. container, due to the exceeding length, which does not fit into the maximum length dimension of the semi-trailer.

On most semitrailer chassis, additional twistlocks are fitted in the center of the chassis to allow single 20 ft. containers to be transported. This loading pattern is common for heavy transports as the weight is distributed on more axles, compared to front or rear stowage.

Intermodality

In comparison with a boxed semitrailer, which could be equipped with lifting bars along the sides, a container chassis can hardly be considered as an intermodal transport unit as it cannot be handled with ordinary equipment. On the other hand, there is no reason to include the chassis in the intermodal chain, especially not for rail transports, since it could be separated from the cargo transport units. This is not the case with boxed semitrailers and for that reason, the whole vehicle must be considered as a cargo transport unit if it should be transported in intermodal networks. There is, however, a possibility that container chassis may be used for sea transports on roll-on roll-off vessels, which have no opportunities to stow individual containers. In such transport networks the chassis could become intermodal if it is equipped with lashing fittings used for deck securing. Despite that, the container chassis should be considered as a monomodal transport unit, used mainly for road transports.

Disadvantages

The disadvantage with container chassis is that they have no equipment for loading and unloading of containers, like hook lift trucks, side lifters and swap-body chassis. This could be a problem if the chassis has to stay passive for a considerable time due to loading or unloading operations, which has a negative effect on the utilization level. For transports between terminals this would probably be a minor issue, since the availability of handling equipment is relatively high. The problem could be more obvious for transports to and from places with limited access to suitable handling equipment, like log dumps. In that regard, containers used in biofuel transport chains have to be stowed on the chassis during loading and unloading at the dump, as well as during standby, since handling equipment usually aren’t available.

3.2.1.3 Swap-body chassis

Swap-body chassis are used for road transports of swap-bodies. These are common in two different versions, either with the wheels separated towards the ends or with the wheels combined in the middle. The latter design requires additional support legs in order to stand upright during parking.

Figure 30 Swap-body chassis with outer wheels (cargobull.com)

Figure 31 Swap-body chassis with centered wheels (cargobull.com)

What distinguishes a swap-body chassis from a container chassis, disregarding cargo capacity, is the ability to change the vertical height. The height of the chassis is controlled with pneumatic pressure, which fills and empties the air bellows. This is an essential feature for swap-body chassis since this allows loading and unloading without other handling equipment.

Loading pattern

The swap-body chassis is included in the European modular concept, where all transport units have been standardized in length, width and height in order to suite certain road regulations in different countries. This means that a swap-body chassis should be capable of carrying swap-bodies with standardized dimension, smaller chassis for C-class units and larger chassis for A-class units. If the chassis is fitted with a twistlock arrangement, it usually requires one setup only since the twistlock locations should be the same within each class, even if the overall length varies slightly between different models.

A swap-body chassis is not capable of carrying two units simultaneously, for example two A715 units on a large chassis. The reason for this is the limitations given in the road regulations, which usually do not allow modules with such dimensions.

Loading technique

The loading and unloading operations are possible since the swap-body is equipped with four legs. These legs can be adjusted in the vertical direction and the upper part is squared outwards in order to create free space below the floor. With this design the vertical parts of the legs are located outside the longitudinal sides of the swap-body, which is required when the chassis shall pick up or drop the unit.

Figure 32 Legs on a swap-body (omnibuss.se)

When a swap-body shall be picked up, it has to be standing on its four legs. The chassis is then driven under the unit and is placed where the locking arrangement matches that on the swap-body. When the chassis is in position, the chassis is raised by filling the air bellows. When the swap-body has lifted off the ground, the legs are retracted and the unit is ready for transport. The unloading procedure is made in the same way but in the opposite order. The whole operation takes just a few minutes.

Application markets

Since the weight capacity of a swap-body is lower than for a standardized container in the same length class, these units are not suitable for heavy cargoes. The capacity is lower because the construction is weaker, which makes it cheaper to build but less compatible with certain types of cargoes.

For countries which allow road trains with a length of 25.25 m, the swap-body isn't optimal since it doesn't utilize the maximum allowed length, based on the C-class dimensions. To utilize the maximum length, a combination of A and C class units is required.

At this point there are no swap-bodies available for intermodal transports of biofuels, which could be explained by limited weight capacity and low strength in side walls. However, in a volume capacity perspective swap-bodies would be an interesting concept since they are slightly wider and higher than standard ISO containers, which increase the volume. Swap-bodies are also slightly longer than corresponding container classes, which increases the volume capacity even further.

3.2.1.4 Side lifter

The side lifter is a combined transport and handling vehicle used for transports of standard ISO containers. What's unique with the side lifter construction is that it doesn't require an external lifting device for loading and unloading, which makes it very useful in places with poor infrastructure.

Loading patterns
The side lifter can normally carry one 40 ft. container or two 20 ft. containers on board the chassis, which use to be 13.6 m in length – equal to the size of an ordinary semitrailer. If two 20 ft. containers are loaded they have to be locked together with a special linking device, allowing the side lifter to lift them as if they were a single 40 ft. unit.

Figure 33 Side lifter for containers (trailermag.com)

Loading technique
The loading and unloading procedures are possible by two hydraulically powered lifting cranes, one on each fore and aft end of the container(s). The lifting cranes are mounted directly onto the chassis but can normally be moved along the chassis to fit different container sizes. The cranes are also fitted with two legs, one on each crane, which are retracted to the ground before the lifting procedure commences. These are used to stabilize the handling since the trailer chassis wouldn't be able to bear the weight of a fully loaded container without tipping over, since handling is done in the trans-

verse direction. The container is connected to the lifting cranes by four chains, one in each lower twistlock corner. These chains are easily connected to the corner posts and the whole lifting procedure takes just a few minutes.

Figure 34 Side lifter in operation (trailermag.com)

Application markets

Since a considerable weight is transferred to the legs during lifting, the system could be difficult to adopt in transport chains where loading or unloading are done at places with soft ground. It is therefore possible that the side lifter concept would face a lot of issues in intermodal biofuel transports, where heavy loadings in the terrain could be required. The problems with soft ground are even greater during raining periods, where the legs risk sinking into the ground. One solution could then be not to unload the containers in the terrain, but have them stowed on the trailer during filling. But that affects the utilization level of the chassis and lifting cranes negatively, and at the same time weakens the motives to have side lifters in these kinds of transport chains – when the cranes aren't used.

The applications of the side lifter vary between different manufacturers but common features are; trailer to trailer transshipments, trailer to train transshipments and double stacking.

Figure 35 Transshipment of containers between train and trailer (businessreviewaustralia.com)

Disadvantages
A disadvantage with the side lifter concept is the weight of the lifting cranes. Since the permissible weight of road vehicles vary between different types of roads and between different countries, additional weight of the vehicle means less weight in cargo. In other words, the transport cost may increase if the additional weight of the lifting cranes reduces the amount of cargo carried during a specific transport leg. The loss in transport efficiency should however be put in relation to the gain achieved by improved handling.

Another aspect which may affect the applicability of side lifters for biofuel transports is the investment costs. The lifting cranes are inactive for a considerable time and that means bad utilization levels and high capital costs. That should be compared to the alternative arrangement where external lifting devices are used in the terrain, at the intermediate terminals and at the end consumer, which could reach higher utilization levels provided the cargo flow is high enough.

For countries which allow road vehicles with a length of 25.25 m, the side lifter concept could be problematic since the lifting cranes use to be fitted on the semitrailer chassis only. That means that the additional vehicle module will not have the ability to load and unload containers in the same way as the semitrailer, which creates a non-harmonized concept with two different handling techniques.

3.2.2 Railway wagons

Railway wagons exist in many different versions and it is not possible to make a review of them all, especially not since the product range changes between countries and different railway companies. It is, however, necessary to have an accurate review of the most common railway wagons used in intermodal transports by rail, since the railway is essential for the concept of combined transports.

Container and swap-body wagons
Containers and swap-bodies are usually transported on the same types of wagons during railway transports. Historically, ISO-containers have been common in two different lengths, 20 ft. and 40 ft. while swap-bodies have been common in six different sizes, three in the 20 ft. class and three in the 40 ft. class. During the past decade we have also seen that containers with a length of 45 ft. have been more attractive to transport customers and some believe that these units will increase even further in the future, at least on the European market.[6]

Figure 36 Container and swap-body wagon (legios.eu)

Railway wagons would be easy to optimize for pure container transports since the concept is based on fixed dimensions. A 40 ft. container is twice as long as a 20 ft. container and the width and height dimensions are the same. With these parameters there would be no reason to develop railway wagons longer or wider than the dimensions of the containers. The width is usually no problem since most railways, at least in Europe, have a maximum width which is bigger than the width of a standard container. The height of the wagons is more crucial and that is restricted by the maximum permitted height of the loading gauge used on the actual track. The maximum height of the wagon is defined as restricted height minus height of the container. If the wagon is higher than this limit, the container cannot be transported.

Since containers and swap-bodies use to be transported on the same types of railway wagons, the cargo space is not optimized for containers. Swap-bodies, especially those in class C, are available in three different lengths, 7,15 m, 7,45 m and 7,82 m. Compared to 20 ft. containers, with a length of 6,1 m, these units are about 1 m to 1,7 m longer. This has a negative effect when it comes to the utilization of the whole train length, since it can carry fewer containers due to bigger separation distances between the units. Another problem with combined transports of containers and swap-bodies on

[6] Lars Rexius, Managing director at Unifeeder AB Göteborg

the same railway wagon is that swap-bodies use to have a lower gross weight compared to containers. With lower gross weight capacity, the payload decreases. This means that the railway wagon has a higher weight capacity than what's utilized for transports of swap-bodies. This disadvantage should be put in relation to the benefits achieved by having the ability to use the wagon for more than one type of unit, which increases the flexibility and probably also the return of investment.

The container and swap-body container is equipped with several taps on top of the load surface. These are used to secure the cargo transport unit during the transport by placing the unit on top of these, using the twistlock fittings. They use to be retractable so that the wagon is compatible also for cargo which has no twistlocks built in.

Semitrailer wagons
Railway wagons intended for transports of semitrailers need to be equipped with a lowered part on which the wheel boogie can stand during transport. In comparison with other intermodal cargo transport units, such as containers and swap-bodies, semitrailers can be seen as combined vehicles with an onboard cargo transport unit. As it is not possible to separate these two when the unit is ready for a railway transport, it has a major disadvantage against other cargo transport units, both in terms of dimensions and weight. The wheel boogie contributes to higher tare weights and lesser payload, which normally is no problem for railway transports as the maximum allowed weight use to be higher than for road transports.

Figure 37 Semitrailer wagon (railjournal.com)

Since a semitrailer is higher than other intermodal cargo transport units, including the wheel boogie, it is important that the lowered floor on the railway wagon is as low as possible, otherwise the maximum height limit could be exceeded. A railway wagon intended for transports of semitrailers must also be equipped with a "king-pin tap" in which the king-pin on the semitrailer can be fixed. Without this tap the semitrailer would fall down since it's not allowed to use the front legs during railway transports. These unique fittings and properties make these wagons more expensive than wagons intended for other intermodal cargo transport units.

In order to allow semitrailers to be transported on rail, these units must be equipped with lifting bars on each side of the unit, like these found on a swap-body. The unit can then be handled by lifting trucks equipped with grapple arms, which is the most common handling technique found in combined road/rail terminals. Other lifting techniques have been developed but shown not to be commercially operational yet, such as lifting below the wheel boogie and the king pin. To be operational in the existing concept, the semitrailer must also have a retractable collision protection in the rear end. With these requirements, few European semitrailers are fully compatible with intermodal transports.

Roll container wagons (with rotation benches)
Railway wagons intended for transports of roll containers are based on a technique called ACTS, Abroll Container Transport System, which was developed by the Dutch company Translift. The main concept is that the road vehicle shall be able to load and unload roll containers to and from the railway wagon on its own, without other assistance.

The ACTS technique is simple and requires a rotation bench on top of the railway wagon. The bench should be equipped with two horizontal lanes on which the roll container can slide during handling. During loading and unloading, the bench shall be rotated outwards, around 45 degrees from the centerline of the wagon and the container is then pushed or drawn in the longitudinal direction.

Figure 38 Roll off container wagon (vagongyar.hu)

In order to have a good vertical fit between the wagon and the road vehicle, the height of the wagons uses to be around 1 350 mm, even if the actual height could vary slightly. Compared to a standard wagon intended for carriage of containers and swap-bodies, this is about 20 cm higher, which is equal to the height of the rotation bench. The fact that wagons for roll containers are higher than ordinary wagons is important since it affects the utilization level negatively. Railway tracks have height restrictions due to bridges, tunnels etc. and the train unit must not be higher than this limit, otherwise the train set is not fit for transports within that railway network. That's why it is important to minimize the height of the wagon as much as possible, so that the height of the cargo can be as high as possible. In this regard, roll container wagons have a major disadvantage against other intermodal cargo transport units, since the usable cross section within the loading gauge decreases.

3.2.2.1 Common wagons in the Green Cargo fleet

The following intermodal railway wagons are used in services by the Swedish railway operator Green Cargo, which is one of the major operators acting on the Swedish market. Wagons which begin with the letter "L" are constructed for carriage of containers and swap-bodies while wagons which begin with the letter "S" are constructed for carriage of containers, swap-bodies and trailers.

GREEN CARGO WAGON FLEET		
	Type	**Number of units**
1	Sgnss	925
2	Lgjns	780
3	Lgns	413
4	Lgjns-wk	199
5	Sdgms	199
6	Lgns for 2x20'	186
7	Sdggmrs (T2000)	149
8	Sdggmrss (Twin)	149
9	Lgjns-w	100
10	Sgns	76
11	Lgjs	49
12	Sgmmns	26
13	Lgs-x	19
14	Sgs	3
15	Sgnss-v	1

Table 3 Number of wagons in Green Cargo's fleet (Green Cargo)

Type	Cont. 10 ft.	Cont. 20 ft.	Cont. 30 ft.	Cont. 40 ft.	Cont. 45 ft.	Swap 7.15 m	Swap 7.45 m	Swap 7.82 m	Trailer 13.6 m	Roll-off container 6 m
Lgjns	-	2	-	1	1	2	1	1	-	-
Lgjns-w	-	2	-	1	-	2	1	1	-	-
Lgjns-wk	-	2	1	1	-	1	1	1	-	-
Lgjs	-	2	1	1	-	1	1	1	-	-
Lgns	-	2	-	1	-	2	1	1	-	-
Lgns for 2x20’	-	2	-	-	-	-	-	-	-	-
Lgs-x	-	-	-	-	-	-	-	-	-	2
Sdgms	-	2	1	1	1	2	2	2	1	-
Sdggmrs (T2000)	-	4	-	2	2	4	4	4	2	-
Sdggmrss (Twin)	-	4	2	2	2	4	4	4	2	-
Sgnss-v	-	-	-	-	-	-	-	-	-	3
Sgns	-	3	2	1	1	2	-	-	-	-
Sgnss	-	3	2	1	1	2	-	-	-	-
Sgmmns	4	2	-	1	-	-	-	-	-	-
Sgs	-	3	-	-	-	-	-	-	-	-

Table 4 Number of units per wagon

Lgjns

Railway wagon “Lgjns” is intended for carriage of containers and swap-bodies and is equipped with hydraulic shock absorbers and retractable twistlock taps. The wagon is 1 180 mm high and the cargo surface length is 15 840 mm.

Figure 39 Lgjns (kbwj.se)

Lgjns-w

Railway wagon "Lgjns-w" is intended for carriage of containers and swap-bodies and is equipped with hydraulic shock absorbers and retractable twistlock taps. The wagon is 1 175 mm high and the cargo surface length is 15 860 mm.

Figure 40 Lgjns-w (kbwj.se)

Lgjns-wk

Railway wagon "Lgjns-wk" is intended for carriage of containers and swap-bodies and is equipped with hydraulic shock absorbers and retractable twistlock taps. The wagon is 1 180 mm high and the cargo surface length is 14 260 mm.

Figure 41 Lgjns-wk (Green Cargo)

Lgjs

Railway wagon "Lgjs" is intended for carriage of containers and swap-bodies and is equipped with hydraulic shock absorbers and retractable twistlock taps. The wagon is 1 180 mm high and the cargo surface length is 13 540 mm.

Figure 42 Lgjs (svjvbild.se)

Lgns

Railway wagon "Lgns" is intended for carriage of containers and swap-bodies and the units is equipped with retractable twistlock taps but not with hydraulic shock absorbers. The wagon is 1 165 mm high and the cargo surface length is 14 660 mm.

Figure 43 Lgns (goederenwagens.nl)

Lgns 2x20’

Railway wagon “Lgns 2x20’” is intended mainly for carriage of 20 ft. wood chip containers. The wagon is equipped with fixed twistlock taps which could be used for standard 20 ft. containers as well. The wagon is 1 269 mm high and the cargo surface length is 12 620 mm.

Figure 44 Lgns 2x20’ (Green Cargo)

Lgs-x

Railway wagon “Lgs-x” is intended mainly for carriage of roll-off containers and for that reason the wagon is constructed with two rotation benches which can be rotated 45 degrees towards the sides. Loading and discharging can then be done from a truck with handling equipment for roll-off containers. This process takes just a few minutes. The wagon is 1 375 mm high and 2 600 mm wide – which is equal to the maximum allowed width for road transports according to current regulations. The cargo surface length is 2 x 6 210 mm.


Figure 45 Lgs-x (Green Cargo)

Sdgms

Railway wagon “Sdgms” is intended for carriage of semi-trailers, containers and swap-bodies. The wagon is 1 170 mm high for containers and 310 mm high for trailers. The cargo surface length is 16 450 mm.

Figure 46 Sdgms (postvagnen.com)

Sdggmrs (T2000)
Railway wagon "Sdggmrs" is intended for carriage of semi-trailers, containers and swap-bodies. The wagon consists of two units which are interconnected by a third boggie in the middle part. The wagon is 1 155 mm high for containers and 270 mm high for trailers. The total cargo surface length is 2 x 16 230 mm.

Figure 47 Sdggmrs (goederenwagens.nl)

Sdggmrss (TWIN)
Railway wagon "Sdggmrs (TWIN)" is intended for carriage of semitrailers, containers and swap-bodies. The wagon consists of two units which are interconnected by a third boggie in the middle part. The wagon is 1 155 mm high for containers and 270 mm high for trailers. The total cargo surface length is 2 x 15 761 mm.

Figure 48 Sdggmrss (Green Cargo)

Sgnss-v
Railway wagon "Sgnss-v" is intended for transports of roll-off containers. For that reason the wagon is constructed with three rotation benches which can be rotated 40 degrees towards the sides. Loading and discharging can then be done from a truck with handling equipment for roll-off containers. The wagon is 1 350 mm high to the rotation bench and the cargo surface length is 3 x 6 180 mm.


Figure 49 Sdgnss-v (Green Cargo)

Sgns

Railway wagon “Sgns” is intended for carriage of containers and swap-bodies. The wagon is 1 155 mm high and the cargo surface length is 18 400 mm.

Figure 50 Sgns (rail-pictures.com)

Sgnss

Railway wagon “Sgnss” is intended for carriage of containers and swap-bodies. The wagon is 1 155 mm high and the cargo surface length is 18 400 mm.

Figure 51 Sgnss (Green Cargo)

Sgmmns

Railway wagon “Sgmmns” is intended mainly for carriage of containers and is equipped with retractable twistlock taps. The wagon is 1 640 mm high and the cargo surface length is 18 400 mm.

Figure 52 Sgmmns (goederenwagens.nl)

Sgs

Railway wagon “Sgs” is intended mainly for carriage of containers. The wagon is 1 640 mm high and the cargo surface length is 19 500 mm.

Figure 53 Sgs (nordpilen.se)

3.3 Axle load limits – weight restrictions

It’s not only the physical dimensions that have to be fulfilled in order to access certain transport routes, the carrier also has to fulfill the requirements of maximum axle load. This restriction may vary between different parts of the transport network, based on the load capacity determined by the quality found in the underlying construction.

The design of the carrier as well as the number of axles determine the load capacity for the carrier, more axles will normally allow more weight but also the distance between the axles may affect the actual capacity.

For volumetric cargo the weight restrictions normally do not affect the utilization level, as it is difficult to load quantities that exceed this limit – without first exceeding other restrictions such as the height, width and length dimensions. But what's important is to develop transport vehicles as well as cargo transport units that are as light as possible, as heavy units may increase the risk of affecting the utilization level also for cargo loaded by volume.

3.3.1 Road vehicle

Swedish roads are divided into three weight categories, BK1, BK2 and BK3, where BK1 represents 95% of the public road network.[7] The maximum allowed weight on these roads is 60 ton but the actual capacity for a specific vehicle combination is determined by a number of different parameters, including number of axles and axle distances. For vehicles in international traffic on Swedish roads, the maximum weight is however limited to 40 ton for road trains with five or six axles and 44 ton for a three axis truck with a two or three axis trailer – carrying one 40 ft. ISO container. For such transports the vehicle must not exceed 16.5 m in length for a tractor with semitrailer combination and not 18.75 m for a truck and trailer combination.

3.3.2 Railway wagon

In Sweden, the railway load capacity is expressed in two ways – STAX for maximum axle load and STVM for maximum allowed wagon weight per meter. The majority of the Swedish railway network has a STAX capacity of at least 22.5 ton per axle and a STVM capacity of 6.4 ton per meter, which is the Swedish standard. The Swedish Transport Administration is however working on the implementation of higher capacities and there are already railway tracks available for axle loads up to 25 ton and STVM 8 ton per meter.

In the following table, the cargo capacity has been calculated for different railway wagons found in the Green Cargo fleet. The capacity is expressed for different speeds; 100 km/h and 120 km/h, which are based on STAX 22.5 ton.

[7] Transportstyrelsen, Lasta lagligt – Vikt- och dimensionsbestämmelser för tunga fordon, p. 3

Type	Tare (ton)	Cargo capacity at 100 km/h for axle load limit 22.5 ton (ton)	Cargo capacity at 120 km/h for axle load limit 22.5 ton (ton)
Lgjns	12.0	33.0	-
Lgjns-w	12.5	32.5	-
Lgjns-wk	12.0	33.0	-
Lgjs	11.8	28.0	-
Lgns	11.2	33.5	-
Lgns for 2x20’	10.0	35.0	-
Lgs-x	13.3	22.7	-
Sdgms	20.5	59.5	-
Sdggmrs (T2000)	35.0	100.0	-
Sdggmrss (Twin)	35.0	100.0	85.0
Sgnss-v	28.5	-	61.5
Sgns	20.0	70.0	-
Sgnss	20.0	70.0	60.0
Sgmmns	17.7	62.3	-
Sgs	22.5	57.5	-

Table 5 Cargo capacity for different types of railway wagons

Figure 54 Axle load limits for the Swedish railway network

4 Cargo transport units – an analysis of existing concepts for biofuel transports

The cargo transport unit is a very important component in intermodal transport chains. Since the concept of intermodality is that one and the same unit is to be transported in several different transport modes, it has to be designed with great applicability – otherwise it will be difficult to handle in an efficient way. For that reason, various standards have been developed in order to reduce the number of cargo transport units used within the intermodal transport network.

4.1 Common types of cargo transport units

In a general view, cargo transport units can be divided into three different categories; containers, swap-bodies and trailers. In an intermodal perspective, the container is probably the most familiar CTU available and it is the only CTU that is highly suitable for sea, road and rail transports.

Cargo transport unit	Length (mm)	Standard height (mm)	Width (mm)	Tare (ton)	Payload (ton)	Volume (m^3)
Container						
10 ft.	3 050	2 440	2 440	1.40	8.80	16.0
20 ft.	6 100	2 590	2 440	2.35	28.26	33.0
20 ft. ”High cube”	6 100	2 900	2 440	2.35	28.26	37.4
30 ft.	9 140	2 590	2 440	3.20	28.30	51.0
40 ft.	12 190	2 590	2 440	3.70	28.84	64.0
40 ft. “High cube”	12 190	2 900	2 440	4.02	28.84	76.4
45 ft. pallet wide	13 720	2 900	2 500	4.59	28.84	86.0
Roll-off container						
20 ft. standard	6 000	2 400	2 450	2.96	-	35.0
Swap-body						
A1212	12 120	2 670	2 550	4.4	23.5	74.0
A1250	12 500	2 670	2 550	4.5	23.2	76.0
A1360	13 600	2 670	2 550	4.9	22.8	80.0
C715	7 150	2 670	2 550	2.4	11.4	43.0
C745	7 450	2 670	2 550	2.5	11.4	45.0
C782	7 820	2 670	2 550	2.6	11.4	50.0
Trailer						
EU-semitrailer	13 600	2 670	2 550	7.5	25.0	90.0

Table 6 Different cargo transport units with typical dimensions (source: VTI 676)

4.1.1 Containers

The container was first introduced in the United States of America during the 1950's and today it is one of the most usable cargo transport units available on the transport market, especially for sea transports. The container is standardized by the "International Organization for Standardization" (ISO) and the container dimensions are based on the maximum loading gauge allowed for road transports in the US. For such transports, the width shall not exceed 2.44 m and the height shall not be higher than 2.59 m. However, a modified container with a height of 2.90 m, known as "high cube", has been developed in order to meet the commercial demand.

Figure 55 Example of a 20 ft. ISO container (sopcontainer.se)

4.1.1.1 Disadvantages

One of the biggest disadvantages with the ISO container is that it does not fit well into the European road network. Most countries within the European Union allow road vehicles with a maximum width of approximately 2.55 m, which is slightly wider than the standard container dimensions. When an ISO container is transported on European roads, it does not fill the whole width and that is unsatisfying in terms of transport efficiency. At the same time, the ISO container is not suitable for high utilization with EUR pallets, which makes it difficult to load in an efficient manner. To solve this, a wider container with a width of 2.50 m has become popular, especially in combined road transports as it is more or less equal to the dimensions of a standard trailer. These units are known as "pallet wide" containers.

Due to the firm structure the container has a relatively high light weight, tare, which affects the payload negatively. For road transports, where the maximum gross weights use to be the lower limit for the intermodal transport chain, it is not unusual that the containers are overloaded. That increases the road wear. If the tare weight had been lower, each container would be capable to carry more cargo without breaking the maximum gross weight set up in the national road regulations.

Another disadvantage with the container is that it can lock the transport vehicle if no handling equipment is available at the place of loading or unloading of cargo. In these cases, usually in connection to road transports, the container has to be stowed on the vehicle if it cannot be handled with available equipment. That affects the utilization of the vehicle in a negative way, since it cannot be used for other transport work during this time.

4.1.1.2 Advantages

A major advantage with containers is the possibility of stacking. The container is built in accordance with the requirements found in sea transports, where it has to be able to stack in order enable efficient stowing on board. However, in other transport modes, the stacking possibilities can be used for rational terminal storage. When the units are able to stack, the terminal area required for handling could be reduced in size. With a stronger framework the container becomes more robust, which makes it less exposed to physical damage. A firm structure can also give better protection to the cargo, both from weather and bad handling.

Figure 56 Container stacking (thaiworldview.com)

The container is heavily used for intermodal transports, which is a great benefit since it allows a high level of availability. With more units in circulation it is easier to find a unit nearby and that reduces the positioning costs, which is crucial for low valued cargoes.

With standardized dimensions and components, the container has a great benefit when it comes to handling. Since the available handling fittings are pre-defined, each operator in the intermodal transport chain can expect what they have to offer in order to handle the container at their facility. This pre-knowledge is one important factor why the container has been so successful and widely used. In addition to handling facilitation, standardized handling also allows shorter transshipment times. Less time for loading and unloading of each unit means higher frequencies and increased handling capacity.

When the external dimensions of a cargo transport unit are standardized, it is possible to optimize the whole transport chain for maximum utilization.

For example, railway wagons can be developed with lengths, widths and heights that result in a reduction of void spaces within the train length. When each wagon is optimized for a set of containers, without void spaces in-between, the train set can carry more containers on the same length as a train set used for heterogeneous cargo transport units. More units mean lower transport cost per unit. This reasoning is applicable also for other modes of transports, such as road and sea transports. The latter one is perhaps the most optimized transport mode available for containers since container vessels allow tight stowage in both the horizontal and vertical directions.

A standard ISO-container has a relatively low manufacturing cost and that affects the purchase price for the end customer. With lower capital costs the transport becomes less cost sensitive, which increases the potential of high utilization of the unit.

4.1.1.3 Handling

The container is easy to handle and to secure, which are very important factors in terms of efficiency. The handling and securing processes are also similar in all three transport modes, which is unique in comparison with other cargo transport units. This makes it quite simple when it comes to the construction, as it does not need to have access to special handling or securing arrangements for different types of applications.

A standardized ISO-container is equipped with 8 twistlock corners, 4 at the bottom and 4 at the top. The upper corners are used mainly for lifting and securing of above stacked containers while the lower corners are used mainly for securing. In some cases, for example when the unit is handled by a side lifter truck, the container can be lifted by chains attached to the lower corners. All twistlock corners are strong enough to bear the weight of the container during lifting and securing, both in loaded and unloaded conditions. Securing and lifting through the corners is possible by twistlocks.

Figure 57 Twistlock corner castings (monohakobi.com)

Traditionally, the container is handled by a crane or truck which is equipped with twistlocks. The container is then lifted through four corner posts located on top of the container, corner posts on the opposite side are used for securing and usually not for lifting. Some containers may also be equipped with two fork lift tunnels located in the middle, but this is optional and therefore not required by the ISO standard. Containers with fork lift tunnels are well-suited for transports where the shipper or receiver does not have access to advanced lifting technology, for example small to medium sized industries.

Figure 58 A reachstacker lifting a 40 ft. container (konecranes.com)

4.1.2 Roll-off container

A roll-off container is a cargo transport unit suitable for intermodal transports, but the original purpose was to develop a system that could be self-managed by single road vehicles, especially in areas where there is a lack of available equipment. Today, the system is used mainly in bulk transports, such as waste, gravel, biofuels and recycling products. It is quite common for transports of construction waste from building sites in cities as the unit is easy to handle and does not require additional handling equipment or plenty of room.

The system is based on a hook-lift technique where a level arm is placed on the truck. The roll-off container is equipped with two steel rollers located in the rear end of the unit and a grapple located in the front part. These devices represent the basic structure of the roll-off concept, which make it unique in comparison with other techniques.

There is a large variety of different roll-off containers available on the market, each with special cargo properties and technical capacities. For heavy products such as gravels, the unit has to be built with stronger materials while a unit mainly used for transports of generic waste could be built with materials that are less strong. The level of additional requirements tends to affect the price, both for complicated structures and extra fittings.

Figure 59 20 ft. roll-off container for waste products (bfab.nu)

4.1.2.1 Disadvantages

Since the weight of the unit is concentrated to a small area at the rear end during loading and unloading, the handling operation could be problematic if the ground is too soft. This could be the case during handling in the terrain and especially during raining periods where the ground may become muddy. Under these conditions, it is possible that the rear end of the roll container sinks into the ground and that the horizontal pulling force helps it to dig even further. One way of dealing with this problem could be not to unload the unit in the terrain, but have it stowed on the chassis during filling. This will, however, affect the utilization level of the chassis in a negative way.

For transshipment to or from railway wagons during intermodal transports, the wagons have to be fitted with a rotation bench that can be pulled out about 45 degrees from the centerline. On this bench the roll-off container should slide during handling. This means that roll-off containers cannot be transported on standard wagons, like combined container and swap-body wagons, which could be a disadvantage in comparison with the container and swap-body concepts. The problem with requirements on non-standardized equipment, or equipment that is less common on the market, is that it could lead to higher operation costs for positioning since it could be more difficult to find suitable carriers in a nearby location. Such factors affect the ability to get economical values of the intermodal concept which could lead to a lower economic difference between the intermodal and monomodal alternatives.

Roll-off containers use to be constructed on the basis of maximum weight and permitted dimensions found in the national road regulations. Roll-off containers optimized for road transports could therefore be difficult to transport in some railway networks, for example class A railways, where the maximum allowed height might be exceeded. This shows that there is a major incompatibility issue between optimized capacities on roads and railways, where it is difficult to get high optimization with intermodal units without investing in non-conventional concepts.

4.1.2.2 Advantages

In a harmonized environment where all components fulfil the requirements in the roll-off container concept, this system has great benefits when it comes to handling. In most intermodal concepts, the cargo transport unit has to be handled by an external lifting truck when the unit is switching from one transport mode to another. In common transport solutions, this is the case for containers, swap-bodies and semitrailers, which are all dependent on the handling technique available at the transshipment node. This is not the case for roll-off containers since the concept itself is developed so that the unit can be transshipped by first level equipment, such as the railway wagon and road carrier. Self-managed handling could therefore lead to reduced capital costs and at the same time lower the operational costs as the process can be done by the truck driver. In theory, this means that there is no need for employees at the terminal.

Most roll-off containers are based on the length dimensions defined by the European modular system, which allow good compatibility with common road carriers, especially in Sweden and other countries which allow road trains. In such truck and trailer combinations it is possible to load three standard roll-off containers, one on the lorry and two on an accompanied semitrailer. For road trains, the roll-off container concept has a great advantage in comparison with containers since the volume capacity use to be higher. It also has an advantage against swap-bodies since only two swap-bodies can be transported in a road train setup due to the length. For ordinary road transports with a truck and trailer, the roll-off container has a disadvantage against the swap-bodies since only two units can be transported in this setup, both roll-off containers and swap-bodies. Since swap-bodies are longer, higher and wider than roll-off containers, swap-bodies have a higher volume capacity.

Figure 60 Three roll-off containers loaded on a road train (ntm.fi)

4.1.2.3 Handling

The loading and unloading procedures on road vehicles are based on a technique where the roll-off container is tilted in the longitudinal direction. This is the essence of the construction which allows the roll-off container to overcome the height difference between the trailer and the ground level, without being lifted from above. This is the most important factor why the roll-off technique isn't suitable for all kinds of goods, especially not for general cargo.

The truck is equipped with a hook which can be moved both in the longitudinal and vertical directions. By placing the truck right in front of the roll-off container, which is placed in the longitudinal direction as well, the hook grabs the container and starts tipping it upwards and forward. Before the center of the container has reached the back of the trailer chassis, it slips on the wheels mounted on the rear end of the container. When the center has been reached, the container is leveled over the trailer edge and is then pulled forward until it is fully positioned on the chassis. During this maneuver the container slips over wheels on the rear edge of the trailer and full length contact between container and trailer is achieved first when the container is in position at the front.

Handling of roll-off containers on railway wagons requires a rotation bench on which the roll-off container stands during transport. The bench should be able to rotate about 45 degrees from the centerline of the wagon in order to get access to the grapple on the front. When the bench is rotated outwards, the road carrier places just in front of the roll-off container and the built-in hook arm is connected to the grapple. When in position, the hook arm starts to drag the roll-off container towards the road carrier, which uses the rear rollers for sliding. When the roll-off container is in position, the loading process is finished and the rotation bench can be pulled back in position. The whole process takes just a couple of minutes and everything can be done by the truck driver. Unloading of roll-off containers from the truck to the railway wagon is done in the same way but in the opposite direction.

Figure 61 Standard roll-off containers loaded onto a railway wagon (greencargo.se)

4.1.3 Swap-body

A swap-body is an intermodal cargo transport unit which is developed for combined transports on road and railways. There are a variety of swap-bodies available on the market and in comparison with a standard container, the dimensions are slightly larger – both in height, length and width. It is fitted with four legs which enables direct loading and unloading by a single truck or trailer.

4.1.3.1 Different types of swap-bodies

Swap-bodies can be divided into two categories, A & C, where A is an extended version of a 40 ft. ISO container and C is an extended version of a 20 ft. ISO container. Each category offers modified units with different lengths. Height and width are traditionally the same for all versions. Swap-bodies in category C have a length between 7.15 – 7.82 m, which is about 1 to 1.5 m longer than an ordinary 20 ft. container. With these dimensions, the swap-body is well suited for the European Modular system (EMS, as they fit into the maximum permissible dimensions for road combinations in the European Union. In a road train with a maximum length of 18.75 m, two swap-bodies can be carried, one on the truck and one on a trailer.

For countries which allow longer truck and trailer combinations, it could be difficult to combine swap-bodies in an efficient way. As they do not fit within the dimensions of a standard semitrailer of 13.6 m, three swap-bodies in category C cannot be carried simultaneously. A similar set-up would be possible to load with three 20 ft. ISO containers, which would utilize the whole space within the permissible dimensions. Swap-bodies in category A are more or less equal to the length of a standard 40 ft. container, which fits within the dimensions of a standard semitrailer.

Figure 62 A swap-body resting on its legs (evansdist.com)

4.1.3.2 Disadvantages

A major disadvantage with swap-bodies is that they are not designed for stacking. This could be a negative quality compared to a container as terminal stowage will require more space. In this regard the swap-body does not differ from an ordinary trailer, as they both have to be stowed in the horizontal plane. Another issue which is linked to the weak construction is the incapability of being lifted by twistlocks. If the swap-body isn't specifically equipped with upper twistlocks, the unit can only be handled by a reachstacker with four grapple arms, alternatively with a fork truck if the unit is fitted with two fork lift tunnels.

Compared to an ISO-container, the manufacturing cost for swap-bodies is higher. Higher capital cost for the operator and a lower cargo capacity by weight for the transport customer could lead to higher transport costs.

If a swap-body isn't loaded on a chassis during sea transports, it should be required to rest on its legs. Since the legs of a swap-body are too weak to resist the dynamic accelerations without being damaged, such stowage would be difficult to achieve safely. Another dilemma that arises during sea transports of swap-bodies is that the friction between the legs and the ship's deck is too low to eliminate the risk of sliding. With these problems in mind, swap-bodies are not suitable for traditional sea transports, which explain why they are sparsely used in such transport networks.

The contact surface between the legs and the ground is quite small, just around one dm^2 per leg, which means that the weight is concentrated to small resting areas. This could be a major problem for stowage on non-solid ground since the legs may sink if the ground isn't strong enough to support the unit. If the swap-body is loaded or unloaded by a truck, even small vertical variations could result in handling difficulties, since the chassis requires free space between the legs in order to maneuver to and from the unit. With this in mind, swap-bodies are not ideal for transports of biofuels since these transports may require loading and unloading in the terrain, where the ground could be very soft. These problems are even bigger in raining periods and it is difficult to imagine how the swap-body could fit into the transport chain during such circumstances. At the same time it is not realistic to offer other handling techniques in the terrain, such as fork lift trucks, since these alternative methods would decrease the cost efficiency and simultaneously affect the motives to use swap-bodies for biofuel transports.

4.1.3.3 Advantages

Swap-bodies are designed to enable low tare weights, which means that less material is used compared to a standard container. When less material is used the unit becomes lighter and the load capacity increases.

A major advantage with the swap-body is that it can be dropped off from a road vehicle without any need for additional handling equipment. This is beneficial because fewer components have to be engaged in the handling process, which results in lower costs for the operator. It is also beneficial for the road vehicle since the unit can be dropped off or picked up even if no other handling equipment is available. In comparison with an ISO-container, which requires external lifters, the road vehicle can be engaged in other transport missions while the swap-body is loaded or unloaded. That affects the capital costs of the vehicle in a positive way.

Figure 63 Handling of a swap-body (bayer-sohn.de)

For terminal handling, usually on a railway yard, most swap-bodies can be handled with grapple arms fitted onto a reachstacker. Some swap-bodies can also be equipped with two fork lift tunnels in the middle, which could be an alternative if the unit has to be transported within an area where no grapple arm trucks are available, for example at an industry.

Swap-bodies are developed for high compatibility with the dimensions of EUR-pallets. In comparison with ISO-containers, which are incompatible with these dimensions, swap-bodies allow higher utilization levels and better loading patterns for transports of EUR-pallets. This improves the transport economy as well as the handling of the goods, as it is easier to load and unload the unit.

4.1.3.4 Handling

For railway transports, swap-bodies are handled by vertical lifting to and from the wagons. The most common lifting technique is based on grapple arms, which requires that the swap-body is equipped with four lifting bars, two on each side of the unit. These lifting bars are equal to those found on a semitrailer intended for intermodal transports, which is a benefit in comparison with other available lifting techniques since it allows great operability. Swap-bodies can also be equipped with fork lift tunnels, either as a single lifting device or in combination with lifting bars, where the latter option is the most common.

A swap-body can be secured with twistlocks when being stowed on a rail or road vehicle. This is a quick and simple operation, especially on railway wagons where the twistlocks usually do not have to be locked in order to keep the unit safe. Railway wagons intended for transports of containers and swap-bodies are normally equipped only with twistlock pins, on which the unit can be placed through its twistlock corners.

Figure 64 Handling of a swap-body with a reachstacker (jernhhusen.se)

The loading and unloading operations by road vehicles are possible since the swap-body is equipped with four legs. These legs can be adjusted in the vertical direction and the upper part is squared outwards in order to create free space below the floor. With this design the vertical parts of the legs are located outside the longitudinal sides of the swap-body, which is required when the chassis shall pick up or drop the unit.

When a swap-body shall be picked up by a road vehicle, it has to be standing on its four legs. The chassis is then driven under the unit and is placed where the locking arrangement matches that on the swap-body. When the chassis is in position, the chassis is raised by filling the air bellows. When the swap-body has lifted off the ground, the legs are retracted and the unit is ready for transport. The unloading procedure is made in the same way but in the opposite order. The whole operation takes just a few minutes.

4.1.4 Semitrailer

A semitrailer is a cargo transport unit developed for road transports. What differentiates a semitrailer from other types of cargo transport units is that it is fixed to a vehicle, in this case the trailer chassis. The semitrailer is built in accordance with European dimensions with a length of 13.6 m and a width of 2.55 m, which is allowed in all European countries. For tempered trailers, a width of 2.60 m is accepted in some of these countries.

Semitrailers use to have two or three wheel axles depending on the configuration. The number of axles is important when it comes to the maximum allowed gross weight according to the national road regulations. Generally, more axles allow higher gross weights since the weight is distributed over a wider area on the road, which reduces the pressure compared to equal weights but fewer axles. Simultaneously, more axles increase the tare weight of the semitrailer and result in higher capital costs.

The semitrailer is driven by a single truck or lorry, depending on which module combinations are accepted in the national legislation regarding the maximum truck length. The truck or lorry is easily connected to the semitrailer via a king-pin located below the front part of the unit. For a road train where the semitrailer is connected to a lorry, an intermediate boogie has to be used since the semitrailer has no wheels in the front, called a dolly. When connected to a truck, the front part rests on the back of the truck and no dolly has to be used.

Figure 65 Example of a dolly (truck1.eu)

Even if the semitrailer is built for road transports it can be used as an intermodal unit in other transport modes such as sea and railway transports. For sea transports, RoRo vessels are the most common ship type, which stands for Roll on Roll off. In a RoRo vessel, the trailer is rolled on and rolled off via ramps on the quay. This can be done either by the truck driver for accompanied trailers, or by the port personnel for unaccompanied trailers. For railway transports, the semitrailer is loaded and unloaded by the terminal operator, using lifting cranes for handling. For such handling, the semitrailer has to be fitted with lifting bars on each side of the trailer.

4.1.4.1 Disadvantages

In some cases it could be a disadvantage not to be able to separate the cargo transport unit from the trailer chassis. This could be the case during loading or unloading of cargo at an industry, where not only the capital cost for the cargo transport unit is charged but also the costs of the chassis. Other intermodal cargo transport units, especially swap-bodies, can be dropped off from the truck or trailer while being loaded or unloaded with cargo. In these cases, the truck or trailer can be engaged in other transports during the loading or unloading process, which minimizes the passive time for these units.

When semitrailers are to be transported by rail there are special requirements on the railway wagons. The biggest difference against other types of wagons is that it has to be fitted with a lowered floor on which the wheel boogie can stand during transport. This leads to a construction which requires more steel, which make the wagons heavier than comparable wagons. With more material required, the manufacturing costs increase. Theoretically, a heavier unit will also decrease the payload capacity, even though this is a minor problem since railway tracks use to have higher weight capacities than road tracks.

Figure 66 Example of a semitrailer wagon (dybas.de)

The semitrailer is not stackable, which is a major disadvantage against the container. Non-stackable units have to be stowed in the horizontal plane, in terminals and on board ships, which requires a larger physical area than stackable units. This means that fewer units can be stowed in the same space as stackable units. In terminals that results in higher fixed costs and on board a ship that may lead to lower utilization and higher operation costs.

4.1.4.2 Advantages

Since the cargo transport unit is fixed on top of the trailer chassis there is no need for vertical handling when the unit has to be dropped off or picked up by another truck. This means that the semitrailer can be put aside and be standing by itself when not in transport. The loading and unloading process can be done quick and easy by the truck driver and there is no need for external equipment or personnel. This keeps the operation costs low.

The semitrailer concept is highly standardized which means that the number of different models is limited. This is a major advantage since it allows the cargo transport unit to be widely used without risks of incompatibility. All semitrailers are secured to the truck or lorry via a king-pin which is located below the front part and this technique is compatible with all semitrailers used in Europe. Connecting and disconnecting to or from the truck are the main operations required in the handling of the semitrailer unit. However, besides the physical connection or disconnection of the king-pin, the driver has to connect or disconnect the pneumatic cables which are used to control the brakes on the semitrailer. Also the front legs have to be raised or lowered manually by the driver.

There is a good availability of trucks and lorries which can be used for transports of semitrailers in Europe. With good availability there is a good chance to find a truck nearby, which results in lower costs for positioning, which could make the transport more competitive against other dedicated transport systems where longer positioning distances are required. Low transport costs could be crucial for transports of low valued cargo and in these cases highly standardized systems like the semitrailer have great advantages.

4.1.4.3 Handling

Handling of semitrailers between different trucks is easy and quick. The semitrailer is connected to the truck by the king-pin located below the front part of the unit, which is a standardized fitting for such transport units. Additional work has to be done for connection and disconnection of the pneumatic cables for the brakes as well as for handling of the front legs, which are used for support.

Semitrailers used for intermodal transports have to be equipped with certain fittings in order to allow handling within these transport chains. These requirements are different depending on the actual mode of transport.

For sea transports, the semitrailer has to be secured against the deck in order to reduce the risk of unintended movements, which could lead to catastrophic results if not managed in a proper way. For this purpose, the semitrailer should be equipped with dedicated attachment points for lashings, located on both sides of the trailer. For stability, the built-in front legs are not constructed to give enough support to the semitrailer during sea transports as they are too small in width, which increases the risk of tipping. To give sufficient support, a trailer trestle with a wider support width has to be placed in the front part.

Figure 67 Trailer trestle and lashing chains attached to the trailer on board a ship (northlinkferries.co.uk)

For rail transports, the semitrailer has to be liftable since most terminals load the units from above. This means that the semitrailer has to be equipped with some sort of lifting device and the most common technique for that purpose is grapple arm lifting. The grapple arm technique requires that the semitrailer is fitted with four lifting bars, two on each side of the unit. These bars are equal to those found on an ordinary swap-body, which is a benefit in comparison with other available lifting techniques since it allows great operability. To allow intermodal transports of semitrailers on rail, the unit must also be equipped with a retractable collision protector, which is found in the rear end of the unit. Common types of railway wagons intended for carriage of semitrailers are not constructed for semitrailers without a retractable collision protected.

Figure 68 Handling of a semitrailer with a reachstacker (jernhusen.se)

4.2 Cargo transport units suitable for transports of biofuels

All cargo has its own characteristics and depending on factors like cargo value, handling techniques and applicable transport solutions, the requirements on the cargo transport unit can vary. For most cargoes, like machineries, paper reels and furniture, standardized cargo transport units like containers, semitrailers and swap-bodies are well-suited. For other kinds of cargoes, like bulk cargoes, these cargo transport units are not so well-suited. One reason for this could be that general cargo transport units have a lower volume capacity than what's requested in an economic perspective for bulk cargoes. Another reason could be that these units are difficult to load and unload with bulk cargoes as they are constructed for horizontal loading and unloading via the side doors. In most cases, bulk cargoes are easier to load in the vertical direction and unload in either the vertical or horizontal direction.

Figure 69 Horizontal loading of a container (eureka-trading.com)

To optimize intermodal transports of bulk cargoes, specialized cargo transport units have been developed over the years. Depending on the properties of the actual cargo, the structure of the cargo transport units can be modified, both in length, width, height and strength. For heavy bulk cargoes, like gravels, the structure has to be more robust than for light weighted cargoes such as waste. A more robust structure tends to be heavier due to more material use, which could affect the payload negatively.

There are several different intermodal concepts available for transports of biofuel in bulk. Many of these are based on dimensions which are similar or equal to the dimensions of standardized cargo transport units such as containers and swap-bodies. The lengths seem to correspond to the length of a 20 ft. ISO container, the height with high cube containers and the width with swap-bodies. One explanation to this could be that the unit is maximized in all directions based on the restrictions found in the national road regulations, at least in a Swedish perspective.

With the same length as a container, three units can be carried on a road train compared to two units of swap-body lengths. With increased height and width, the unit can utilize the loading gauge on Swedish roads in a more efficient way, without exceeding the restrictions in the national legislation. Such a unit has therefore a higher volume capacity than standardized units. This is a very important factor since biofuel products tend to be low value cargoes. With higher capacities, the transport cost per cubic meter can be lowered, which affects the competitiveness for intermodal transports in a positive way.

In the following table, cargo transport units suitable for intermodal transports of biofuel products, have been identified.

Cargo transport unit	Length (mm)	Standard height (mm)	Width (mm)	Tare (ton)	Volume (m^3)
Container					
WoodTainer XXL	6 100	2 900	2 550/2 900	2.90	46.0
WoodTainer XXXL	6 100	3 115	2 550/3 355	3.10	58.0
InnoFold F20	6 100	2 900	2 550	2.90	41.0
Roll-off container					
FRINAB Flis Elit 38 ISO	6 225	2 983/2 908[8]	2 560	2.82	38.0
CMT Opticont Allround	6 200	3 075	2 550	2.15	39.0
CMT Opticont FlisMax	6 200	3 075	2 600	1.98	45.0
CMT Econt	6 060	3 075/3 000[9]	2 600	2.80	40.0

Table 7 Cargo transport units for wood biofuels

[8] Height for container with retractable rolls
[9] Height for container with retractable rolls

The standard price for wood chip containers with a capacity of 40 m3 usually lie between 55 000 SEK and 60 000 SEK. Wood chip containers are normally manufactured with thinner steel plates than standard bulk containers, but with higher quality in order to increase the capacity but lower the tare weight. This results in higher purchase prices for the customer. Containers with a capacity of about 35 m3 are normally not customized for transports of wood chips and most of these are built for allround purposes. Such units have a slightly stronger construction with 3 mm steel in the side walls and 4 mm steel in the bottom, in addition to vertical profiles attached to the structure in order to make it more robust. The price for allround containers usually lie around 50 000 SEK.

A wood chip container can normally be used for about 10 years, but the lifespan can vary depending on the actual services and level of maintenance. Typical maintenance actions consist of lubrication of moving parts and painting, unless the container isn't exposed to damages.

Some wood chip containers are built with capacities of about 45 m3, without exceeding the dimensions found in the national road regulation (Sweden). In order to increase the capacity from 35 m3 (allround containers) to 45 m3, these units use to be lengthened, from 6.1 m to 6.2 m. Also the height is increased, from about 2.4 m to nearly 3.0 m, just to exceed the maximum allowed height for road transports when being stowed on chassis with standard heights.

4.2.1 The Innofreight concept

The Austrian company Innofreight has during the past decade developed cargo transport units that are volume optimized for light weighted bulk cargoes, called the Innofreight concept. These units have been a commercial success and there are a lot of industries using their technique for smooth and efficient bulk transports.

For transports of wood chips, Innofreight has patented a concept called the WoodTainer system. This system consists of two major components; customized containers and a unique unloading technique. The containers are available in different lengths, widths and heights but the most common unit is based on the dimensions of a 20 ft. container, with a length of 6.1 m. However, the mid-part section of this container is somewhat wider than a standard container, so is the height, which is equal to the height of a high cube container.

Since all Innofreight containers used for transports of wood chips have a fixed length of 6.1 m, they fit well into the modular concept of intermodal cargo transport units. Since most container and swap-body wagons for railway transports have a maximum length of 60 ft. that means three Innofreight containers can be carried per wagon. On European road carriers, used in countries which do not allow road trains, two containers can be loaded. In countries which do allow road trains, like Sweden, three containers can be loaded on a carrier utilizing the maximum length of 25.25 m.

Generally, all Innofreight containers have a volume capacity which is larger than for standard containers, which is a major advantage in comparison with other transport techniques. The WoodTainer units are free from moving parts, which reduce the maintenance costs and the risk of failures.

The unloading of all wood chip containers is based on a tipping technique where the container is rotated upside down, 180 degrees from the upright position. Since the containers are open top, unless hard top covers are used, the wood chips fall out by itself, without manual handling. This unloading technique is very effective and the whole unloading process takes just a couple of minutes. To be able to rotate the containers, these have to be fitted with two fork lift tunnels. In addition to these, a dedicated rotation fork has to be installed on the truck, a device which is patented by Innofreight.

Figure 70 Discharging of an Innofreight container (Innofreight.com)

Innofreight components such as containers and rotation forks cannot be purchased, instead Innofreight has chosen to offer their products through renting. Innofreight is also quite restrictive when it comes to sharing information, such as prices. The combination of these two factors makes it difficult to do economic analyzes of the concept and to compare it with other concepts available on the market.

For terminals with a very large transport flow, Innofreight has developed a stationary WoodTainer unloading equipment. Instead of rotating the container during unloading, the stationary equipment uses the forks to lift the container and pull it to a parallel track where the content is discharged into a large bin. This process is very efficient and in full service the system can handle up to 1 000 m3 per hour. The system can be operated by one person only and the train set is shunted automatically by a shunting robot.

Figure 71 The stationary unloading equipment in service (innofreight.com)

4.2.1.1 WoodTainer XXL

The WoodTainer XXL is based on the dimensions of a 20 ft. high cube container, with expanded width. The upper part of the container has a width of 2.55 mm, which is the standard maximum width for transports on European roads, while the mid and lower parts have a width of 2.90 m. The volume capacity reaches 46 cubic meters and the tare weight is approximately 2.9 ton. Fully loaded the container weights about 17 ton, when loaded with wood chips with a density of 0.3 ton per cubic meter. A total of 2 400 WoodTainer XXL containers have been manufactured since it was introduced, resulting in more than 1 million unloadings.[10]

To increase the volume capacity as much as possible within the external dimension limits, the WoodTainer XXL has not been fitted with a flat floor, which is possible since the cargo is formable. The floor height is reduced to a minimum based on the strength requirements and there is no steel plates attached to the upper part of the beams. This open structure allows wood chips to fill out the space between the beams, which increase the volume. The fork lift tunnels are raised inside the unit, which contribute to a non-horizontal floor. This construction is well suited for bulk cargoes but on the contrary, it could be difficult to use for other types of cargoes. This is a major disadvantage when it comes to the evaluation of utilization level and cost efficiency, since the WoodTainer units risk to be used only for transports in one direction, from the forest to the terminal or the heating plant.

[10] Innofreight broschure – WoodTainer XXL

Figure 72 Inner view of an Innofreight container (Flodén)

The WoodTainer XXL is optimized for the European railway network, which is the reason why the upper part of the container doesn't have the same width as the mid and lower parts. With the current dimensions, the container can be transported on all class GC railways in Europe, unless the units are loaded on wagons which are higher than standard wagons.

In a Swedish perspective, where larger loading gauges are used than in other European countries, the dimensions of the WoodTainer XXL are not ideal since the loading gauge capacity is higher than what's utilized by the system. This is the case on both class A and class C railways, where the effect is much greater on class C railways. To solve this capacity issue, Innofreight has developed a steel frame section that can be placed on top of the container, which increases the height and the internal volume. The volume increase is approximately 20% compared to the original volume.

The steel frame is easily placed on top of the twistlock corners, which keep it in place during transport. A problem which has been observed in transport chains using this steel frame is that it can easily be damaged during filling.[11] Innofreight containers are usually loaded by front wheel loaders, which have a limited elevation capacity for their buckets. With a standard WoodTainer XXL, the bucket can easily be placed above the container during wood chip filling and the bucket does not come in contact with the container. With a container equipped with the additional steel frame there is a much higher risk that the bucket smashes the frame at some stage in the filling process. Therefore, it is not uncommon that the steel frames are damaged to some extent, which increases the maintenance costs for the operator. People that operate the front wheel loaders have also claimed that the steel frames inhibit their work.[12]

[11] According to a Swedish representative from the energy company E-ON, during a reference meeting in Gothenburg on the 4th of April 2014.
[12] According to a reference meeting in Gothenburg on the 4th of April 2014

Figure 73 A WoodTainer XXL fitted with the additonal upper frame (innofreight.com)

One of the biggest disadvantages with the WoodTainer XXL is that it cannot be used in ordinary intermodal transport chains due to the current width restrictions on European roads. In Sweden, the maximum allowed width is somewhat higher than in other European countries, 2.60 m compared to the standard width of 2.55 m. In Sweden, the 2.60 m width is allowed if the cargo is wider than the vehicle. Due to these restrictions, the WoodTainer XXL is not allowed to be carried on road vehicles. There is, however, a possibility to apply for an exception from the road regulations for units which have to be transported by road in some part of the transport chain. This exception request shall be sent to the Swedish road administration and if it is approved, an exemption order can be issued. The road vehicle shall then be properly fitted for the transport, provided with signs that mark the additional width and signs with the text “bred last” placed in the centerline of the vehicle. These signs shall be fitted in both longitudinal directions, forward and rearward.

Figure 74 Transport of Innofreight containers on a Swedish road (innofreight.com)

A transport which has been approved for an exception is allowed to be executed only on roads mentioned in the request. Exemptions are therefore not a general solution that can be used to make WoodTainer XXL units better suited for intermodal transports. In most cases, the exemption is valid only during a certain period, after which a new exception request has to be made. The additional work required in the exemption process, in combination with the restricted operation area and limited timeframe, could make these transports ineffective in an administrative perspective.

The innofreight system could have a negative impact on the transport flexibility since it requires more planning than other transport methods. The transport operator cannot be sure that the Swedish road administration will issue an exemption for the actual transport, which could require a backup plan. To have other transport solutions standby in cases of rejected requests could simultaneously lead to higher costs. At the same time, the transport operator cannot be sure how long time the Swedish transport administration will need to process a request, which is another uncertain factor in the WoodTainer concept.

4.2.1.2 WoodTainer XXXL

In addition to the WoodTainer XXL, Innofreight has developed another container with a volume capacity of about 58 cubic meters, which is about 25% higher than for the WoodTainer XXL. This unit is known as the WoodTainer XXXL.

The length of the WoodTainer XXXL is equal to a 20 ft. container, 6.1 m, but the width is increased to 3.35 m for the mid part section, with a minimum width of 2.55 m for the upper and lower parts. The height is also increased to 3.11 m and the tare weight is approximately 3.1 ton. The increased dimensions are based on the loading gauges found in the Swedish railway network and the unit is compatible for transports on class C tracks. This means that the unit can be highly utilized for railway transports in Sweden but it could be problematic to ship it to other countries in Europe, where the maximum dimensions are lower for most parts of the network. However, since new railway tracks in Europe are built for larger units, class GC tracks, the WoodTainer XXXL could be more compatible for international transports in the future.

Figure 75 WoodTainer XXXL on a railway wagon (innofreight.com)

At present, it's uncertain how many WoodTainer XXXL units Innofreight has manufactured over the years, but initial research have shown that it has a low presence in transports of biofuels in Sweden. The product is not available on Innofreight's website and generally, it is very difficult to find any information about this unit. All units which have been identified have been operated by the Swedish railway operator Green Cargo, which has no published information either.

One of the biggest disadvantages with the WoodTainer XXXL concept is the weight in loaded condition. In most cases, the Innofreight containers are handled by a fork lift truck even if it is possible to use the built-in twistlock castings. The reason is the ability to discharge the content fast and effective. The WoodTainer XXXL is handled in the same way as the WoodTainer XXL during discharge, using the rotating forks, but what's unique to the WoodTainer XXXL concept is that an ordinary truck has a capacity that is too low for safe handling of the XXXL unit. This means that the biofuel terminals have to make investments in heavier trucks in order to handle XXXL units. Heavier trucks are more costly to operate and they have a higher capital cost. However, in an overall perspective these costs could gain the transport chain since more biofuel can be handled, which reduces the cost per cubic meter. The problem is that most containers in the biofuel transport fleet is not of the XXXL type, which make the trucks oversized for handling of units with ordinary dimensions.

Figure 76 Handling of a WoodTainer XXXL (innofreight.com)

4.2.1.3 InnoFold F20

InnoFold is another cargo transport unit suitable for transports of biofuel products such as wood chips. The container is developed by Innofreight and is based on the same unloading technique found in the WoodTainer concept. The dimensions are based on a 20 ft. high cube container, with a length of 6.1 m and a height of 2.9 m. The width, however, is increased to 2.55 m, which is equal to the maximum allowed width for road vehicles within Europe. The volume capacity is 41 cubic meters and the tare weight is 2.9 ton.

Figure 77 Loaded InnoFold F20 container (innofreight.com)

What's unique with the InnoFold container is that it is foldable in the vertical direction. This is possible since the hold is made of textile, which is designed as a big bag. The container is raised and retracted by a fork lift truck, using straps located on top of the container. In a retracted state, three containers can be stowed on top of each other, in the same space as a raised one. This is a great benefit in terms of transport efficiency, especially when the units are to be transported empty between two locations.

Figure 78 Retracting of the InnoFold container (innofreight.com)

In addition to the fork lift tunnels located in the middle of the unit, the InnoFold container is fitted with four lifting bars which are used for grapple arm handling. Trucks with grapple arms are common in railway terminals used for combined transports since they are capable to lift containers, swap-bodies and semitrailers in an efficient way. However, the lifting bars cannot be used to unload the container when it is loaded with wood chips or other bulk cargoes. For such handling, a fork lift truck with rotating forks has to be used, which means that the lifting bars are interesting only for pure transshipment operations between different transport modes.

Figure 79 The InnoFold container in closed condition (innofreight.com)

The InnoFold container differs from other cargo transport units found in the Innofreight product range, in terms of maintenance and durability. Compared to the WoodTainer concept, the InnoFold container is fitted with movable parts which require frequent maintenance in order to sustain functioning. With an increased need for maintenance, the operating costs increase as well. The durability of the construction is also uncertain since there is no information available from real operations, but it’s reasonable to suppose that these units are more exposed to damage than other cargo transport units based on a fixed structure, like the WoodTainer containers.

Figure 80 Handling of an InnoFold container (innofreight.com)

4.2.2 FRINAB Flis Elit 38 ISO

FRINAB Flis Elit 38 ISO is a cargo transport unit which has been integrated in the ISO system by introducing ISO components on a roll-off container. The main purpose with the Elit 38 is to offer a system which is easier to utilize for different kinds of cargoes and in different modes of transport.

Traditional roll-off containers developed for transports of bulk cargoes could be difficult to use for non-bulk cargoes since they are handled through backward tilting. In major railway terminals it is unusual to handle cargo transport units with the roll-off technique, mainly because they are uncommon in intermodal transports but also because they require specialized railway wagons. To handle separate roll-off containers in a railway terminal which is focused on container and swap-body units could be ineffective since they require other handling equipment. Therefore, it is hard to utilize bulk containers in traditional intermodal transports, in which non-bulk cargoes use to be handled. Based on this fact, the Elit 38 has taken advantage of other available handling techniques and integrated these on an existing roll-off container. This increases the flexibility for the operator, which could lead to lower overall costs and higher transport efficiency.

The Elit 38 is equipped with three common handling fittings, twistlocks for container transports, grapple arm and rollers for hook lift handling, and two fork lift tunnels for generic lifting. With these fittings, the unit is a lot easier to handle in ordinary intermodal terminals.

Figure 81 Outer view of the Flis Elit 38 ISO container (bfab.nu)

The Elit 38 has a volume capacity of 38 cubic meters, which is 3 cubic meters more than a standard roll-off container. The length is 6.22 m, the width is 2.56 m and the height varies between 2.90 m and 2.98 m. The reason for variations in height is that the container is equipped with retractable rolls, which can be raised when the unit is transported as a container. The tare weight is 2.82 ton.

The Elit 38 is an open top container which is easily loaded from above. The rear end is fitted with doors and the container could be discharged in the same way as a standard roll-off container, through backward tilting using the hook arm on the carrier.

Figure 82 Inner view of the Flis Elit 38 ISO container (bfab.nu)

4.2.3 CMT Opticont Allround

CMT Opticont Allround is a cargo transport unit suitable for transports of bulk cargoes such as waste, wood chips, scrap and grain. The container is larger than a standard roll-off container, with a length of 6.2 m, a width of 2.55 m and a height of 3.07 m. The volume capacity is about 39 cubic meters and the tare weight is approximately 2.15 ton.

The CMT Opticont Allround is based on the roll-off technique and must be handled by a hook lift truck since no other handling devices are installed. On the other hand, this unit is not built primarily for intermodal transports and the width and height dimensions are optimized for road transports. As an intermodal cargo transport unit the area of operation is strongly limited since the unit is too large to be transported on class A railways in Sweden, which is the most common railway track as of today. There is, however, a possibility to transport these units on class C railways as well as GC tracks for European transports.

The CMT Opticont Allround is an open top container which is easily loaded from above. The rear end is fitted with doors and the container is discharged in the same way as a standard roll-off container, through backward tilting using the hook arm on the carrier.

Figure 83 Opticont Allround (cmt.se)

4.2.4 CMT Opticont FlisMax

CMT Opticont FlisMax is a cargo transport unit developed for optimized transports of wood chips or other bulk cargoes with low densities. The design is unique since it is turned inside out, where the longitudinal beams have been placed on the inside. With this structure, the outer sides become flat while the inside volume is increased. The container is built with high quality steel which gives a good strength and a low tare weight, which is an important factor when the volume increases to a level where the maximum weight could be critical.

Standard roll-off containers use to have several vertical beams located on the outer sides of the unit, up to 10 beams per side. In a fuel economy perspective, these beams create turbulence and high resistance against the air. According to calculations, the resistance of such designs is equal to an additional braking area of one meter per side.[13] As the CMT Opticont FlisMax design eliminates the need of outer beams, the fuel economy is improved. It is estimated that a road carrier saves about 5% of fuel for transports with CMT Opticont FlisMax, compared to transports with the traditional roll-off containers, which is an economic and environmental benefit.

Figure 84 Example of a FlisMax roll-off container (cmt.se)

The CMT Opticont FlisMax container is larger than a standard roll-off container, with a length of 6.2 m, a width of 2.6 m and a height of 3.07 m. The width is based on the upper limit found in the Swedish road regulations, where 2.6 m is allowed for road vehicles including cargo. To pass this limit, all additional fittings are placed on the inside, like attachment points for top covers. Since the unit is wider than the road vehicle, it has been marked with red and yellow signs at the extreme width, both forward and backward.

The CMT Opticont FlisMax has a volume capacity of 45 cubic meters, which is more or less equal to the capacity of Innofreight's WoodTainer XXL, which has been very successful for railway transports. In comparison with other cargo transport units suitable for transports of low density cargoes, the volume capacity is increased by 15%. This is noticeable since the only dimension

[13] SSAB – Vända sidor ökar åkarens vinst

which has been modified is the width, which is increased from 2.55 m to 2.60 m.

The CMT Opticont FlisMax is based on the roll-off technique and must be handled by a hook lift truck since no other handling devices are installed. On the other hand, this unit is not built primarily for intermodal transports and the width and height dimensions are optimized for road transports. As an intermodal cargo transport unit the area of operation is strongly limited since the unit is too large to be transported on class A railways in Sweden, which is the most common railway track as of today. There is, however, a possibility to transport these units on class C railways as well as GC tracks for European transports.

Figure 85 Tipping of a FlisMax roll-off container (abroll.de)

The CMT Opticont FlisMax is an open top container which is easily loaded from above. The rear end is fitted with doors and the container is discharged in the same way as a standard roll-off container, through backward tilting using the hook arm on the carrier.

4.2.5 CMT Econt

CMT Econt is a cargo transport unit which has been integrated in the ISO system by introducing ISO components on a roll-off container. The main purpose with the Econt is to offer a system which is easier to utilize for different kinds of cargoes and in different modes of transport.

Traditional roll-off containers developed for transports of bulk cargoes could be difficult to use for non-bulk cargoes since they are handled through backward tilting. In major railway terminals it is unusual to handle cargo transport units with the roll-off technique, mainly because they are uncommon in intermodal transports but also because they require specialized railway wagons. To handle separate roll-off containers in a railway terminal which is focused on container and swap-body units could be ineffective since they require other handling equipment. Therefore, it is hard to utilize bulk containers in traditional intermodal transports, in which non-bulk cargoes use to be handled. Based on this fact, the CMT Econt has taken advantage of other available handling techniques and integrated these on an existing roll-off container. This increases the flexibility for the operator, which could lead to lower overall costs and higher transport efficiency.

The Econt is equipped with three common handling fittings, twistlocks for container transports, grapple arm and rollers for hook lift handling, and two fork lift tunnels for generic lifting. With these fittings, the unit is a lot easier to handle in ordinary intermodal terminals.

Figure 86 Handling of an Econt unit with a reachstacker (cmt.se)

The volume capacity for the Econt is somewhat lower than optimized bulk containers such as CMT Opticont FlisMax and Innofreight's Woodtainer XXL. In that sense, Econt has a competitive disadvantage. The volume capacity is 40 cubic meters, which is 5 cubic meters more than a standard roll-off container. The length is more or less equal to a standard 20 ft. container but the height and width dimensions are increased. The container is equipped with retractable rolls, which should be raised when the unit is transported as a container. In retracted mode the height is 3.00 m and in non-retracted mode the height is 3.07 m. The width is based on the maximum width allowed by the Swedish Road administration, 2.60 m for road vehicles including cargo. The tare weight is 2.8 ton, which is higher than other equal CMT units.

The CMT Econt is an open top container which is easily loaded from above. The rear end is fitted with doors and the container could be discharged in the same way as a standard roll-off container, through backward tilting using the hook arm on the carrier.

Figure 87 Handling of an Econt unit with a hook lift truck (cmt.se)

The CMT Econt can be modified with a lot of different accessories such as a top cover, openable side doors etc.

4.3 Transport compatibility for different types of cargo transport units

One important factor to consider for intermodal transports is the compatibility between carriers and cargo transport units. Some carriers are suitable for one type of cargo transport unit while other carriers can be used for several types of cargo transport units.

The following compatibility table is based on the most common transport vehicles available, both in road and rail transports. Green cargo's wagon "Lgjns" is used for containers and swap-bodies, wagon "Sdgms" is used for trailers and "Lgs-x" has been chosen for roll-off containers. For road transports, standard trailer modules are used.

This comparison does not deal with the compatibility between cargo transport units and vehicles, it is only meant to explain whether a certain unit is compatible with current loading gauges or not. The number of units indicates the space potential of each vehicle, regardless of actual capacity.

TRANSPORT COMPATIBILITY - no of units per carrier							
Cargo transport unit	**EU road 16.50 m**	**EU road 18.75 m**	**SE road 25.25 m**	**EU rail GA**	**EU rail GC**	**SE rail A**	**SE rail C**
Container							
10 ft.	4	4	6	5	5	5	5
20 ft.	2	2	3	2	2	2	2
20 ft. ”High cube”	2	2	3	-	2	2	2
WoodTainer XXL	-	-	-	-	2	2	2
WoodTainer XXXL	-	-	-	-	2	-	2
InnoFold F20	2	2	3	-	2	2	2
30 ft.	1	-	1	1	1	1	1
40 ft.	1	-	1	1	1	1	1
40 ft. ”High cube”	1	-	1	-	1	1	1
45 ft. pallet wide	1	-	1	-	1	1	1
Roll-off container							
20 ft. standard	2	2	3	2	2	2	2
Flis Elit 38 ISO	-	-	3	-	2	-	2
Opticont Allround	-	-	3	-	2	-	2
Opticont FlisMax	-	-	3	-	2	-	2
Econt	-	-	3	-	2	-	2
Swap-body							
A1212	1	-	1	1	1	1	1
A1250	1	-	1	1	1	1	1
A1360	1	-	1	1	1	1	1
C715	1	2	2	2	2	2	2
C745	1	2	2	2	2	2	2
C782	1	2	2	2	2	2	2
Trailer							
EU-semitrailer	1	-	1	-	1	1	1

4.4 Performances for different cargo transport units in different modes of transport

In order to evaluate how different cargo transport units perform in different modes of transport, a comparison has been compiled for indicators such as volume capacity per carrier, volume capacity per meter, volumetric utilization, and volume capacity for train sets with a length of 630 m. The maximum volume in different loading gauges has been calculated for different carriers. For rail transports, the volume has been based on a cross section located 1.18 m above the rail, in order to increase the comparability between different carriers.

AREA & VOLUME FOR EACH LOADING GAUGE			
	Loading gauge	**Area (m^2)**	**Volume (m^3)**
Chassis height 1.10 m	Road 16.50 m	7.4	100.6
	Road 18.75 m	7.4	116.2
	Road 25.25 m (h= 4.2 m, w= 2.55 m)	7.9	169.5
Lgins height length 17.10 m	Rail GA (EU)	9.1	144.0
	Rail GC (EU)	11.7	185.3
	Rail A (SE)	10.7	169.5
	Rail C (SE)	12.5	198.0
Sdgms height length 18.34 m	Rail GA (EU)	9.1	166.9
	Rail GC (EU)	11.7	214.6
	Rail A (SE)	10.7	196.0
	Rail C (SE)	12.5	229.0
Lgs- x height length 13.86 m	Rail GA (EU)	9.1	126.1
	Rail GC (EU)	11.7	162.2
	Rail A (SE)	10.7	148.3
	Rail C (SE)	12.5	173.3

TABLE FOR COLOR CODES			
Best performance	2nd and 3rd best	2nd and 3rd worst	Worst performance

4.4.1 Volume capacity on different carriers

The volume capacities for cargo transport units loaded on different carriers are calculated in the table below. The total capacity is the result of capacity per unit and number of units per carrier.

WoodTainer XXXL has the largest capacity for transports on class C and GC railways, Swap-body C782 for EU road 18.75 m, rail A and GA, Opticont FlisMax for SE road 25.25 m and semitrailer for EU road 16.50 m.

VOLUME CAPACITY (m3) volume capacity for different carriers							
Cargo transport unit	**EU road 16.50 m**	**EU road 18.75 m**	**SE road 25.25 m**	**EU rail GA**	**EU rail GC**	**SE rail A**	**SE rail C**
Container							
10 ft.	64	64	96	80	80	80	80
20 ft.	66	66	99	66	66	66	66
20 ft. ”High cube”	75	75	112	-	75	75	75
WoodTainer XXL	-	-	-	-	92	92	92
WoodTainer XXXL	-	-	-	-	116	-	116
InnoFold F20	82	82	123	-	82	82	82
30 ft.	51	-	51	51	51	51	51
40 ft.	64	-	64	64	64	64	64
40 ft. ”High cube”	76	-	76	-	76	76	76
45 ft. pallet wide	86	-	86	-	86	86	86
Roll-off container							
20 ft. standard	70	70	105	70	70	70	70
Flis Elit 38 ISO	-	-	114	-	76	-	76
Opticont Allround	-	-	117	-	78	-	78
Opticont FlisMax	-	-	135	-	90	-	90
Econt	-	-	120	-	80	-	80
Swap-body							
A1212	74	-	74	74	74	74	74
A1250	76	-	76	76	76	76	76
A1360	80	-	80	80	80	80	80
C715	43	86	86	86	86	86	86
C745	45	90	90	90	90	90	90
C782	50	100	100	100	100	100	100
Trailer							
EU-semitrailer	90	-	90	-	90	90	90

4.4.2 Volumetric utilization level

The volumetric utilization levels for different cargo transport units are calculated in the table below. The results are based on the maximum volume available for each carrier in different loading gauges.

WoodTainer XXXL has the largest utilization level for transports on class C and GC railways, Swap-body C782 for EU road 18.75 m, rail A and GA, Opticont FlisMax for SE road 25.25 m and semitrailer for EU road 16.50 m.

VOLUMETRIC UTILIZATION LEVEL (%) utilization of available space in different loading gauges							
Cargo transport unit	**EU road 16.50 m**	**EU road 18.75 m**	**SE road 25.25 m**	**EU rail GA**	**EU rail GC**	**SE rail A**	**SE rail C**
Container							
10 ft.	64	55	57	56	43	47	40
20 ft.	66	57	58	46	36	39	33
20 ft. ”High cube”	74	64	66	-	40	44	38
WoodTainer XXL	-	-	-	-	50	54	46
WoodTainer XXXL	-	-	-	-	63	-	59
InnoFold F20	82	71	73	-	44	48	41
30 ft.	51	-	30	35	28	30	26
40 ft.	64	-	38	44	35	38	32
40 ft. ”High cube”	76	-	45	-	41	45	39
45 ft. pallet wide	85	-	51	-	46	51	43
Roll-off container							
20 ft. standard	70	60	62	56	43	47	40
Flis Elit 38 ISO	-	-	67	-	47	-	44
Opticont Allround	-	-	69	-	48	-	45
Opticont FlisMax	-	-	80	-	55	-	52
Econt	-	-	71	-	49	-	46
Swap-body							
A1212	74	-	44	51	40	44	37
A1250	76	-	45	53	41	45	38
A1360	80	-	47	56	43	47	40
C715	43	74	51	60	46	51	43
C745	45	77	53	63	49	53	45
C782	50	86	59	69	54	59	51
Trailer							
EU-semitrailer	89	-	53	-	42	46	39

Table 8 Volumetric utilization level for different cargo transport units

4.4.3 Volume capacity per meter for different carriers

The volume capacities per meter for cargo transport units loaded on different carriers are calculated in the table below. The total capacity is the result of capacity per unit and length of carrier.

WoodTainer XXXL has the largest capacity per meter for transports on class C and GC railways, Swap-body C782 for EU road 18.75 m, rail A and GA, Opticont FlisMax for SE road 25.25 m and semitrailer for EU road 16.50 m.

VOLUME CAPACITY PER METER (m3) volume capacity per meter for different carriers							
Cargo transport unit	EU road 16.50 m	EU road 18.75 m	SE road 25.25 m	EU rail GA	EU rail GC	SE rail A	SE rail C
Container							
10 ft.	3.88	3.41	3.80	5.05	5.05	5.05	5.05
20 ft.	4.00	3.52	3.92	4.17	4.17	4.17	4.17
20 ft. ”High cube”	4.55	4.00	4.44	-	4.73	4.73	4.73
WoodTainer XXL	-	-	-	-	5.80	5.80	5.80
WoodTainer XXXL	-	-	-	-	7.32	-	7.32
InnoFold F20	4.97	4.37	4.87	-	5.18	5.18	5.18
30 ft.	3.09	-	2.02	3.22	3.22	3.22	3.22
40 ft.	3.88	-	2.53	4.04	4.04	4.04	4.04
40 ft. ”High cube”	4.61	-	3.01	-	4.80	4.80	4.80
45 ft. pallet wide	5.21	-	3.41	-	5.43	5.43	5.43
Roll-off container							
20 ft. standard	4.24	3.73	4.16	5.64	5.64	5.64	5.64
Flis Elit 38 ISO	-	-	4.51	-	6.12	-	6.12
Opticont Allround	-	-	4.63	-	6.28	-	6.28
Opticont FlisMax	-	-	5.35	-	7.25	-	7.25
Econt	-	-	4.75	-	6.44	-	6.44
Swap-body							
A1212	4.48	-	2.93	4.67	4.67	4.67	4.67
A1250	4.61	-	3.01	4.80	4.80	4.80	4.80
A1360	4.85	-	3.17	5.05	5.05	5.05	5.05
C715	2.61	4.59	3.41	5.43	5.43	5.43	5.43
C745	2.73	4.80	3.56	5.68	5.68	5.68	5.68
C782	3.03	5.33	3.96	6.31	6.31	6.31	6.31
Trailer							
EU-semitrailer	5.45	-	3.56	-	4.89	4.89	4.89

Table 9 Volume capacity per meter for different cargo transport units

4.4.4 Volume capacity for train sets with a length of 630 m

The volume capacity for train sets with a length of 630 m is calculated in the table below. The total capacity is the result of capacity per carrier and number of units per train set.

WoodTainer XXXL has the largest capacity for transports on class C and GC railways, Swap-body C782 for rail A and GA.

VOLUME CAPACITY RAIL (m3) volume capacity for a train length of 630 m (615 m without locomotive)				
Cargo transport unit	**EU rail GA**	**EU rail GC**	**SE rail A**	**SE rail C**
Container				
10 ft.	2 800	2 800	2 800	2 800
20 ft.	2 310	2 310	2 310	2 310
20 ft. ”High cube”	-	2 625	2 625	2 625
WoodTainer XXL	-	3 220	3 220	3 220
WoodTainer XXXL	-	4 060	-	4 060
InnoFold F20	-	2 870	2 870	2 870
30 ft.	1 785	1 785	1 785	1 785
40 ft.	2 240	2 240	2 240	2 240
40 ft. ”High cube”	-	2 660	2 660	2 660
45 ft. pallet wide	-	3 010	3 010	3 010
Roll-off container				
20 ft. standard	3 080	3 080	3 080	3 080
Flis Elit 38 ISO	-	3 344	-	3 344
Opticont Allround	-	3 430	-	3 430
Opticont FlisMax	-	3 960	-	3 960
Econt	-	3 520	-	3 520
Swap-body				
A1212	2 590	2 590	2 590	2 590
A1250	2 660	2 660	2 660	2 660
A1360	2 800	2 800	2 800	2 800
C715	3 010	3 010	3 010	3 010
C745	3 150	3 150	3 150	3 150
C782	3 500	3 500	3 500	3 500
Trailer				
EU-semitrailer	-	2 970	2 970	2 970

Table 10 Volume capacity for a train length of 630 m, with different cargo transport units

5 Identified issues and difficulties

Introducing new intermodal concepts for sustainable transports of biofuel products is not an easy task and there are a lot of barriers which have to be managed before an operational system can be delivered. Some barriers are more crucial than others but in a general view there are few practical solutions available on the market, which makes the intermodal transition even tougher. These structural barriers can be divided into three different categories; technical, economic and legal.

5.1 Technical barrier

The technical barrier represents difficulties which can be related to the physical environment, including fixed infrastructure, cargo transport units, transport vehicles and handling equipment. These are highly integrated in intermodal transport chains, which make them sensitive for external changes. In an overall perspective, these set the physical limits of what can be offered in a new transport concept, without risking the ability to take advantage of the existing infrastructure. It is, in other words, not suitable to develop a new concept if it cannot be handled in ordinary transport chains, even if the system would be superb in a technical sense. The technical challenge is therefore to increase the actual capacity and at the same time facilitate handling, without exceeding the technical limits.

Figure 88 Example of a technical barrier on rail (batmanhandbok.w.se)

5.2 Economic barrier

The economic barrier is linked to the profitability of a certain type of cargo transport concept. The economic requirement is very strong and it is likely that no transport concept may survive if it is in conflict with the economic goals. In an extended view, the economic requirement may suggest that the cargo transport unit has to carry quantities which cannot be realized within the technical and legal limits, in order to make it profitable. In such cases there is no market for intermodal transport units and it is then necessary to find other transport options, like multimodal solutions where transshipment is managed in a terminal facility.

5.3 Legal barrier

The legal barrier is determined by the national legislation, which set restrictions for certain modes of transports. Typical restrictions which affect the cargo capacities are maximum length, width and height dimensions as well as axle load and maximum vehicle weights. These restrictions could be related to the capacities in the existing infrastructure such as the technical weight capacities in roads and railways, width and heights of bridges and tunnels as well as safe distances to other vehicles and fixed equipment along the route. The cargo transport unit should therefore not be designed in conflict with these requirements since it could make the unit unusable for most parts of the transport network, where exceptions by the national authority probably would be required for routes where it is going to be used. Such procedures affect the efficiency negatively even though single transports may be executed with higher utilization than possible with standard equipment.

Figure 89 Axle load limit on a Swedish road (trosasund.se)

5.4 Lacking intermodality

Transports of biofuel products are mainly carried out in single or multimodal transport chains and there are few successful examples of fully intermodal transport solutions on the market today. The closest one can get at this stage is probably the Innofreight concept called "WoodTainer", where containers have been designed for increased cargo capacities. The Innofreight container is potentially well-suited for intermodal transports of biofuels since it is fitted with equipment that allows handling with common types of lifting devices, such as twistlock corners and fork lift tunnels.

The problem with the Innofreight container is that it isn't fully intermodal, even though it is equipped as an ordinary ISO container. The reason for this is that it has been redesigned with wider side walls, 2 900 mm instead of

2 440 mm, which makes it non-applicable for road transports where 2 550 mm is the upper limit. Today, the container is therefore used mainly as a cargo transport unit for railway transports, but it could be possible to use for road transports as well if the national road authority approves it. However, such transports are usually limited to certain roads and the unit is then not allowed to be transported outside that network.

The Innofreight container has probably reached success mainly because the efficient unloading procedure as well as the increased capacity, 45 m3 instead of 37 m3 for a standard high cube container with the same external height. Since other fully intermodal concepts have been developed over the years, but none of them with great success, the cargo capacity is probably very crucial. Other intermodal concepts allow smaller quantities than the Innofreight container and that could be one explanation to the low utilization level of such concepts.

5.4.1 Low cargo values

The low cargo value is a major issue for intermodal transports of biofuels since this affects the economical quantities carried in certain types of cargo transport units. With low cargo values it is, however, important that these units are able to carry as much cargo as possible, since more cargo enables lower transport costs. A unit built purely in accordance with the economical demand would therefore, probably, not be operational since it also has to fulfill the technical and legal aspects. In this perspective, the cargo transport unit must be optimized for as much cargo as possible without exceeding the technical and legal framework.

5.4.2 Diverging market demand

One conclusion that can be drawn regarding intermodal transports of biofuels is that the market demand differs between different projects. A suitable transport option may be superb in one transport chain but insufficient in another, which isn't unique to biofuel transports specifically but for the transport sector as a whole. In other words, it can be difficult to find a solution which is suitable during all conditions and the difficulty is to find a design which is a good compromise between different interests. Such units risk not being fully suitable for any transport chain, but on the contrary, they are more flexible since they have more options than highly optimized units. Such flexibility has a value of its own.

The transport distance has probably a big impact on these requirements, since longer transports usually are more cost-sensitive than shorter ones. For long transports it is therefore realistic to assume that the cargo capacity is more crucial than for shorter transports, for which the design of the cargo transport unit becomes very important. In these cases one option could be to apply for road exemptions, where larger units can be transported on certain roads even though they are larger than permitted in the national legislation. However, this would probably be too complicated for transports over short distances, especially if they are performed in non-periodic intervals. Single exemptions are therefore not an efficient method for solving the current capacity issues and for shorter transports, lower capacities might be preferred in order to fulfill the road regulations without exemptions. This illustrates that the requirements may differ in different logistical transport chains.

Another issue that is linked to the diverging market demand is the utilized transport concept. In some projects it could be preferred to use roll-off containers since these enable self-handling, which increases the flexibility. In other projects, where there is no need for unloading at the production site, standard containers could be a better option since the railway terminal has access to own lifting trucks.

5.5 Lacking compatibility

One of the biggest challenges for intermodal transports of biofuels is the lacking compatibility between different modes of transports, especially road and rail transports. This has a historical explanation from the time where all cargo was reloaded before entering a new transport mode. That resulted in divergent standards regarding the physical dimensions and layouts of bridges, tunnels, track widths etc. Today, when cargo transport units are transshipped between different transport modes without internal reloading, that results in bad compatibility and lower cost efficiency.

5.5.1 Incompatible dimensions

Since the road and railway sectors have evolved independently over the past century, few actions have been taken towards increased harmonization. The most obvious difference is the lacking height and width compatibility, where the maximum allowed width is greater for railway vehicles and where the maximum allowed height is greater for road vehicles. This is a fundamental issue which affects the design of intermodal cargo transport units in a negative way. It is, in other words, not possible to construct a cargo transport unit which utilizes the maximum space available within each specific transport mode, without affecting the forthcoming transport negatively, either due to incompatibility or underdimensioned capacity. Also the maximum length dimension could differ between different transport modes, but in general, this dimension has better compatibility than the other two.

For sea transports the physical dimensions have to correspond to the structure of the ship, which varies between different types of vessels. Container ships are built for handling of standard ISO containers, which are determined in height, length, and width. Rolling cargo transported on RoRo ships is mainly restricted in height since the open deck structure enables wide and long units.


Figure 90 Stern ramp on a RoRo vessel (flickr.com)

5.5.1.1 Different railway classes in Sweden

In Sweden there are three different railway classes available, Class A, B & C. Class B railways have a limited spreading and only one route is currently using it in the northern part of Sweden. The other two classes are building up the Swedish railway network, Class A for standard tracks and Class C for extended tracks with dimensions based on the Stora Enso Cargo Unit (SECU). Class C tracks are 200 mm wider and 180 mm higher than Class A tracks and it allows cargo transport units with squared roof corners instead of the tapered roof found on Class A tracks. The latter improvement makes a considerable difference in cargo capacity, especially in combination with increased width and height dimensions. That results in bad compatibility within the railway network itself.

Figure 91 SECU boxes transported by rail (jarnvag.net)

Cargo transport units built for high utilization on Class C tracks cannot be used on Class A tracks while cargo transport units built for high utilization on

Class A tracks result in bad utilization on Class C tracks. Intermodal transports are therefore facing three levels of incompatibility, Road/Rail A/Rail C.

5.5.2 Variations in the railway wagon fleet

Since railway bridges and tunnels are built for a maximum free height, railway wagons must not be higher than this limit, including cargo, otherwise the transport has to be excepted by the national authority. Since the height is determined by the combination of cargo and wagon, increasing height of one unit will consequently result in decreasing height of the other one. In a transport efficiency perspective it is of course necessary to increase the cargo height as much as possible and not the height of the wagon. Higher transport volumes enable better cost efficiency and better profitability. However, the problem is that there are a lot of railway wagons available on the market, which potentially can have an impact on the design of cargo transport units used in biofuel transport networks.

It is easy to distinguish height variations for railway wagons used in different transport concepts, such as the roll-off and container concepts. This can be explained by the additional fittings required on roll-off wagons for enabling easy loading and unloading directly to and from the truck vehicle. Such equipment isn’t required for pure container wagons due to top lift handling. Even though these height variations have a cause, height variations can also be found on wagons within the same concept, for example container wagons. This could be a problem when it comes to the determination of a suitable height on cargo transport units. If the height is dimensioned for the lowest wagons, they cannot be transported on the higher ones. If the height is dimensioned for the highest wagons, the utilization level will be lower when the units are transported on the lower wagons.

5.5.3 Weight restrictions

In addition to the maximum vehicle dimensions, the capacity is restricted also by limited gross weights. The maximum weight is determined in the national road and rail legislations, which are based on the technical qualities found in different types of road and railway tracks. The quality in Swedish road and railway networks is relatively high and for most transport routes there is no incompatibility regarding weight restrictions. There is, however, a problem when heavy units are transported on single roads or railways, where the quality could be lesser. On these routes it might be possible that the cargo transport unit cannot be fully loaded in order to fulfill the legislative requirements.

Figure 92 Small roads can have lower weight capacities (halmstad.se)

To increase the cargo capacity on transport routes with problematic weight limits, the weight of the cargo transport unit as well as the transport vehicle has to be reduced as much as possible. For every kg which can be subtracted from the cargo transport unit or the transport vehicle, the cargo capacity can increase with an equal amount. The main issue is to find a design that is as light as possible but at the same time fulfills the strength requirements. Such constructions may require higher quality materials which give rise to higher costs.

5.6 Handling techniques

An intermodal transport unit is required to have access to different handling techniques, otherwise it would be difficult to manage within the intermodal transport network. What kind of handling equipment they should be fitted with is however uncertain since different transport chains may require different options. One solution could be to fit the cargo transport unit with the most common fittings, but the problem with such solutions is that it tends to increase the overall cost, which is negative in a cost efficient perspective. In some cases, especially for cargo transport units equipped with fork lift tunnels, the cargo capacity usually decreases since the tunnels are raised inside the unit. That construction applies for Innofreight containers, which in that case is less important since the overall capacity is higher than for other transport solutions due to the increased width. Nevertheless, the capacity could be even higher if the container wouldn't be equipped with such tunnels.

Figure 93 CMT Econt, a cargo transport unit with many handling opportunities (cmt.se)

Transporting Innofreight containers in transport chains which do not use fork lift tunnels for handling is an inefficient transport solution. On the contrary, these units may well be used in future projects where the handling is based on the fork lift technique, which would make them inoperable and perhaps unutilized if other suitable projects cannot be found. Such issues would affect the long term utilization negatively, even though the utilization in the short term isn't optimal. Such considerations have to be made.

The requirements on available handling techniques are probably higher at the production site than in transshipment terminals, mainly because there is less volume to handle, which affects the economical motives for external lifting trucks. In a terminal, it could be difficult to achieve high utilization for external lifting trucks as well, but in a comparison it would probably be easier than increasing the utilization level for lifting trucks stationed at the production site. In that regard, it is important to determine whether it is necessary to unload the cargo transport units in the terrain or if they can be stowed on board the vehicle during filling.

For cargo transport units loaded onto a semitrailer chassis, the capital cost for the chassis would probably be a minor adding to the overall cost, which should be compared to the additional costs for an internal or external handler. The problem could be greater if a cargo transport unit is loaded onto a truck, which has no separate chassis that can be dropped off. During such circumstances, the capital cost for the complete road train, truck and semitrailer chassis, will be added to the overall cost. In that case, a handling technique which allows self-managed handling could be a suitable option, for example a roll-off container concept where all cargo transport units can be unloaded to the ground. For such concepts, the road vehicle is able to increase the utilization level, which reduces the capital costs and opens up for fewer trucks due to higher transport frequencies.

5.7 Icing

Some biofuel representatives, such as Johanna Enström at SkogForsk, have stated that wood chips may be subject to icing during transports. Fresh wood chips contain moisture and if it is loaded into a cargo transport unit before drying, the wood chips may freeze to a solid lump in the bottom of the unit. In the worst case, this lump may build up a massive layer in the bottom, which could be difficult to remove during ordinary discharge. Some units, such as the Innofreight container, are rotated upside down during the discharging procedure, which may be sufficient to release non-adherent ice layers, if not, special vibrators can be installed to facilitate the unloading. The problem may increase for units equipped with fork lift tunnels, like the Innofreight container, since the area on which the ice can adhere usually becomes larger.

Figure 94 Ice layer on the bottom of an Innofreight container (mariterm)

Adherent ice layers which cannot be removed in an efficient way may increase the operational costs significantly, especially if it has to be removed manually. At the same time, ice layers which are not removed during unloading could easily lead to bad utilization levels due to the fact that more ice is aggregated over time. More ice reduces the utilization level of the cargo space and with less cargo transported, the transport cost will increase.

6 Practical tests with frozen wood chips

A number of practical tests have been carried out to find whether frozen wood chips could be a problem for biofuel transports during winter time. The tests have been done with two squared steel boxes and three different types of wood chips; timber chips, grot chips and stub chips, to simulate the conditions of real transports of wood chips. The steel boxes were painted with two different paints, one with standard paint for ship hulls and one with anti-adherent paint for icebreaker hulls, in order to evaluate adherent differences.

The wood chips had a standard quality and was delivered by Per-Henrik Evebring at Stockarydsterminalen and the steel boxes were delivered by Iulian Olteanu at Oresund Drydocks in Landskrona. The tests were carried out at MariTerm's office in Höganäs during the 30th of June and the 3rd of July 2014. The test documentation can be found in appendix B of this report.

6.1.1.1 Test methodology

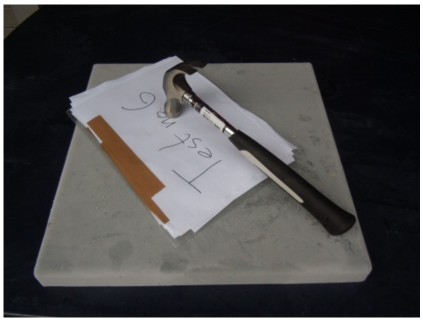
The test was divided into six subtests with three different wood chip qualities. Each wood chip quality was tested with two levels of moisture content, the first one in an unprocessed condition and the second one with added water through showering during 1 hour. The moisture content was calculated based on the weight of dry chips and the actual weight of the test samples.

The following tests were carried out.

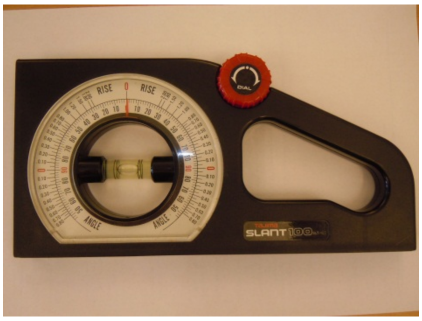
Test scheme		
Test no.	Wood chip quality	Moisture content
1	Timber wood chips	51%
2		54%
3	Grot wood chips	31%
4		47%
5	Stub wood chips	38%
6		58%

		
Timber wood	Grot wood	Stub wood

The wood chips was evenly spread over the box surface and reached a height of about 2 – 2.5 cm. After freezing, the boxes were inclined from 0 – 180° and the test procedure was documented by notes and photographs, which can be found in appendix B. In case where no wood chips released from the steel box up to an inclination angle of 180°, a hammer shock was added to the rear back of the box. The hammer shock was produced by placing the hammer upright at one of the squared edges and then let it fall by its own weight. After the hammer shock, the boxes were raised up to 90° and the results were documented. The following pictures illustrate the hammer sequence.

	
Hammer before shock	Hammer after shock

In cases where the wood chips released before the inclination angle reached 180°, the angle on which the release began was determined by an inclinometer.

	
Inclinometer	Angle measurement

Before a new test was initiated, the steel boxes were cleaned and defrosted.

6.1.1.2 Test results

The tests have shown that freezing of wood chips could be a problem for biofuel transports during winter time. Higher moisture content will make the wood chips more vulnerable for freezing but it has not been possible to determine an exact level on which the freezing effect is lost. However, during a test with grot chips having a moisture content of 31%, no chips were left on the painted surface after the test. When the moisture level increased to 47% the remaining chips increased to 10-75%. This means that moisture content below 31% may not lead to freezing issues. When the moisture level increased to 38% freezing issues were observed and a moisture level of 58% led to 100% freezing. All tests except no. 3 required 180° inclination and an additional hammer shock.

<table>
<tr><td colspan="4">Timber wood chips</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Test no 1 - 180° + hammer</td><td colspan="2">Test no 2 - 180° + hammer</td></tr>
<tr><td>approx. <5% left</td><td>approx. 30% left</td><td>approx. 20% left</td><td>approx. 50% left</td></tr>
<tr><td colspan="4">Grot chips</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Test no 3 - 45°</td><td colspan="2">Test no 4 - 180° + hammer</td></tr>
<tr><td>0% left</td><td>0% left</td><td>approx. <10% left</td><td>approx. 75% left</td></tr>
<tr><td colspan="4">Stub chips</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Test no 5 - 180° + hammer</td><td colspan="2">Test no 6 - 180° + hammer</td></tr>
<tr><td>approx. 5% left</td><td>approx. 40% left</td><td>100% left</td><td>100% left</td></tr>
</table>

The tests have also shown that the surface painting has an effect on the level of remaining chips after discharge. In the tests, two different paints were used, one standard paint and one anti-adherent paint. The anti-adherent paint showed a better resistance to adherent than the standard paint, a result which was constant in four of five tests (test no. 3 excluded). The conclusion of these results is that anti-adherent paints, like these used on icebreaker hulls, could be possible to use for anti-adherent purposes in wood chip containers. To achieve these results a vibrating shock had to be added to the boxes since no release could be observed for inclinations up to 180°, for moisture levels above 38%. This means that vibration is required to initiate a release.

7 Design performances for existing concepts of biofuel transports

Intermodal cargo transport units have to be fitted with certain equipment in order to be applicable in intermodal transport chains. There are several different intermodal concepts available on the market today and the problem could be to decide which concept is the most appropriate for transports of biofuels.

All systems which are built on a technique where units can be transferred from one transport mode to another could be considered as an intermodal transport solutions. There are no problems to develop such systems in theory, but more complicated to take them to reality. Efficient intermodality requires great availability, easy handling, good compatibility, high volume capacity and low costs. These aspects are valid for all types of intermodal transports but for biofuel transports, low costs have probably a greater impact due to low cargo values.

7.1 Availability

Regarding availability, a standard 20 ft. ISO container has great advantages in comparison to other cargo transport units. It's easy to find a unit in a nearby location and they are highly suitable for different types of cargoes. One major issue with cargo transport units dedicated to transports of low density bulk cargoes is that these could be difficult to use for non-bulk cargoes. This increases the risk of bad utilization, which raises the operating costs. On the negative side, a standard container has a relatively high tare weight and a lower volume capacity than a dedicated bulk container.

Standard ISO containers could be difficult to integrate in an intermodal transport chain for biofuels since they have a closed structure. Bulk cargoes such as wood biofuels are preferable loaded from above, either with a bucket or via direct chipping. To load a unit which is intended for horizontal loading, like a standard container, is far more complicated than loading an open top unit. There are, however, transport flows using standard containers for wood biofuels. These units are filled through the doors when the container has been placed with the doors upwards. This method could probably be useful in some flows, but it is certainly not a loading technique which is generally applicable for the biofuel sector as a whole.

In an availability perspective, dedicated cargo transport units could have a disadvantage since they use to be produced in a limited quantity. This affects the possibility to find a unit in a nearby location, which could increase the costs for positioning of empty units. The relation is simple, with less units manufactured there are greater risks not to find a suitable unit within a certain area.

Open top containers are manufactured within the ISO standard and have a relatively good availability, even if it's lower than for standard containers. Therefore it's possible for biofuel transport operators to use open top containers in their intermodal transport flows, as the availability should be greater than for dedicated cargo transport units.

The availability performance for different cargo transport units is summarized in the following table, where the performance has been graded from 1-4 and where 4 is the highest point.

Performance for different cargo transport units							
	Open top HC cont.	WoodTainer XXL	Roll-off container	ISO roll-off container	Opticont FlisMax	Swap-Body C782	Open top tip trailer
Availability	3	1	3	1	1	2	1

Table 11 Availability performance for different cargo transport units

7.2 Handling

Handling of cargo transport units for wood biofuels is divided into two categories, handling of the unit and handling of the cargo. A cargo transport unit which is easy to handle between different modes of transport, but difficult to load or unload with cargo, is not a very good option for transport operators. In these cases, dedicated cargo transport units developed for pure bulk transports have a great advantage compared to general cargo transport units.

For easy loading of cargo there is no reason not to have an open top unit, which can be loaded from the top. Closed cargo transport units are necessary only for transports of sensitive cargoes, but certainly not for bulk cargoes. However, there is a possibility that an open top unit could be more difficult to utilize for other purposes than pure bulk transports. A unit which cannot be used for other transports could have a negative impact on the utilization level. For these cases, an open top unit could be equipped with fittings for removable top covers.

There is no doubt that the WoodTainer XXL has great benefits when it comes to handling. It is equipped with twistlock corners and fork lift tunnels for movements between different modes of transport, which cover most handling equipment available at small to large terminals. On the same time, the fork lift tunnels are used for efficient unloading, using a rotating device.

All roll-off containers are relatively easy to handle. They are loaded from above, emptied from the doors and handled by a hook lift arm. The main difficulty is when the unit is to be transferred to or from a railway wagon, which requires more movements than loading and unloading of twistlock units. During transshipment to or from the wagon, the rotating bench shall be turned outwards and the road vehicle shall be positioned in front of the bench. In this regard, the ISO roll-off container has an advantage compared to the other roll-off container units, since it is equipped with twistlock corners in addition to the traditional roll-off devices. With such equipment, it has the ability to choose which handling technique is the most appropriate for that situation.

Open top containers are easy to transfer between road and rail carriers due to the twistlock fittings. For unloading of bulk cargoes, these units are a lot more complicated to use since they have no good technique for tilting. One way to empty an open top container loaded with wood biofuels is to attach chains to the lower twistlock corners on the opposite side of the doors and start lifting. Another technique is to load the unit onto a tipping trailer. Both techniques are fairly inefficient. This is the case also for swap-bodies, which are relatively easy to handle between different modes of transport but more difficult to unload with bulk cargoes.

The handling performance for different cargo transport units is summarized in the following table, where the performance has been graded from 1-4 and where 4 is the highest point.

Performance for different cargo transport units							
	Open top HC cont.	WoodTain-er XXL	Roll-off container	ISO roll-off container	Opticont FlisMax	Swap-Body C782	Open top tip trailer
Handling	2	4	3	4	3	1	2

Table 12 Handling performance for different cargo transport units

7.3 Compatibility

One of the key factors for great success of an intermodal concept is the level of compatibility between different modes of transport. Some units could have a very high performance in one intermodal transport chain but have compatibility issues in another. Cargo transport units which cannot be used in major intermodal transport networks have a great disadvantage compared to units which have that ability.

Containers, roll-off containers, swap-bodies and semitrailers are all highly compatible with road and railway transports, both in Sweden but also in Europe. A high cube container has a bit lower compatibility than standard containers, with incompatibility with European railways class GA, but apart from that the compatibility level should be considered as high. The compatibility level is not that good for ISO roll-off containers and Opticont FlisMax, which have compatibility issues for European road transports as well as transports on class GA railways. WoodTainer XXL has the worst compatibility level of the cargo transport units studied within this project, with incompatibility on Swedish and European roads as well as on European railways class GA.

The compatibility performance for different cargo transport units is summarized in the following table, where the performance has been graded from 1-4 and where 4 is the highest point.

Performance for different cargo transport units							
	Open top HC cont.	WoodTainer XXL	Roll-off container	ISO roll-off container	Opticont FlisMax	Swap-Body C782	Open top tip trailer
Compatibility	3	1	4	2	2	4	4

Table 13 Compatibility performance for different cargo transport units

7.4 Costs

The quality and technical levels on different cargo transport units affect the capital and operational costs. Since these costs are spread over several transports, they have a minor impact on the total costs for single operations. Generally, the costs are higher for units which are equipped with a lot of additional fittings, which contribute to higher purchasing prices and maintenance costs.

One of the greatest benefits with standard containers is the price level. They have a relatively low purchase price and do not require a lot of maintenance, which keeps the operational costs down. Standard roll-off containers as well as swap-bodies share almost the same cost structure. When it comes to dedicated cargo transport units such as the WoodTainer XXL, Opticont FlisMax and the ISO roll-off container, the costs are higher. The WoodTainer and FlisMax units have unique designs which make them more costly to produce while the ISO roll-off container has a lot of additional fittings which both raise the purchase price and the maintenance costs. The semitrailer differs from the other cargo transport units since there are additional costs for the chassis, which is equipped with a wheel boogie, lamps, tires and a pneumatic system. These fittings raise both the purchase price and the maintenance costs.

The cost performance for different cargo transport units is summarized in the following table, where the performance has been graded from 1-4 and where 4 is the highest point.

Performance for different cargo transport units							
	Open top HC cont.	WoodTainer XXL	Roll-off container	ISO roll-off container	Opticont FlisMax	Swap-Body C782	Open top tip trailer
Costs	4	2	3	2	2	3	1

Table 14 Cost performance for different cargo transport units

7.5 Volume capacity

The volume capacity is probably a crucial factor when a transport operator is deciding which cargo transport unit to use for a certain transport flow. Wood biofuels, as well as other bulk cargoes, are low valued and that's the reason why large quantities are important to achieve high efficiency. A cargo transport unit with a high volume capacity could reduce the need of additional road or rail carriers, which is an economical and environmental benefit. As long as the cargo transport unit doesn't exceed the permitted dimensions in different modes of transports, the volume should be as large as possible, which lower the transport cost per cubic meter.

The WoodTainer XXL and Opticont FlisMax have the highest volume capacities of the cargo transport units studied within this project, which is obvious since they are built for that purpose. A slightly smaller capacity can be achieved for swap-bodies type C782 and semitrailers. The swap-body and semitrailer units are not built for bulk cargoes and today there are no available techniques to use these in intermodal transports of biofuels. It is likely that the volume capacity would be affected negatively if these units should be modified to carry bulk cargoes, but in the existing concepts the volume capacity is relatively high. The lowest capacities are achieved for high cube containers, ISO roll-off containers and standard roll-off containers. High cube containers as well as standard roll- off containers are not designed primarily for low density bulk cargoes, which explain the low volume capacity. The ISO roll-off container has a lower capacity than other cargo transport units developed for low density cargoes since it is equipped with additional fittings that affect the space utilization.

The volume capacity performance for different cargo transport units is summarized in the following table, where the performance has been graded from 1-4 and where 4 is the highest point.

Performance for different cargo transport units							
	Open top HC cont.	WoodTainer XXL	Roll-off container	ISO roll-off container	Opticont FlisMax	Swap-Body C782	Open top tip trailer
Volume capacity	2	4	1	2	4	3	3

Table 15 Volume capacity performance for different cargo transport units

7.6 Summary of design performances

In the following table, all performance levels for different cargo transport units have been compiled. As can be seen, open top containers as well as roll-off containers got the highest rankings while semitrailers got the lowest ranking, all based on the actual performance indicators. It should, however, be noted that this comparison cannot be used as an indicator for which cargo transport unit is the most appropriate for transports of biofuels, but hopefully it gives an indication of how different designs perform compared to other available units.

Performance for different cargo transport units						
	Availability	Handling	Compatibility	Costs	Volume capacity	Total
Open top HC cont.	3	2	3	4	2	14
WoodTainer XXL	1	4	1	2	4	12
Roll-off container	3	3	4	3	1	14
ISO roll-off container	1	4	2	2	2	11
Opticont FlisMax	1	3	2	2	4	12
Swap-Body C782	2	1	4	3	3	13
Open top tip trailer	1	2	4	1	3	11

Table 16 Performance for different cargo transport units

In the following table, the total performance has been summarized, showing the results of the comparison.

Performance for different cargo transport units							
	Open top HC cont.	WoodTainer XXL	Roll-off container	ISO roll-off container	Opticont FlisMax	Swap-Body C782	Open top tip trailer
Total	14	12	14	11	12	13	11

Table 17 Total performance for different cargo transport units

8 Case studies and real examples of biofuel transports

This chapter will focus on logistical concepts found in existing biofuel transport flows as well as transport networks where combined transports have not yet been realized. The latter concepts will be presented as a case studiy, based on real transport flows and actual demand. The aim with this case study is to show how intermodal cargo transport units could be utilized in supply chain networks of biofuels and to define which cargo transport unit is the most appropriate for that purpose.

8.1 Real examples of biofuel transports

Several biofuel terminals have been visited during the project, in order to get real examples of biofuel transports. The most interesting visits are described under this section.

8.1.1 Nykvarn biofuel terminal- an existing biofuel transport solution

Nykvarnsterminalen is a transshipment terminal for biofuels, built in 2009 to supply the biggest bio-powered heating plant in Sweden with biofuel, Igelstaverket in Södertälje. The terminal is located in Nykvarn, about 8 km west of Södertälje and has an annual capacity of 250 000 ton[14], which stands for about 50% of the annual consumption in Igelstaverket.

Figure 95 Loading of wood chips at Nykvarnsterminalen in Södertälje (soderenergi.se)

Nykvarnsterminalen has a large storage capacity and the infrastructure to handle both wood chips and logs. The products arrive to the terminal by rail and are then reloaded to single cargo transport units on road carriers, which are distributed to Igelstaverket by road. The trucks are equipped with Euro 5 engines and the drivers are trained in heavy eco driving, in order to reduce the environmental foot print. The rail tracks are electrified and the rail yard is capable to handle train sets with a length of up to 650 m. With the current production rate, the terminal has transferred 6 250 000 vehicle kilometers from road to rail, which saves 1.8 million liter diesel per year.[15]

[14] Energinyheter - Nykvarns bränsleterminal byggs ut
[15] Tillväxtverket – Biobränsleterminalens kapacitet har ökat väsentligt.

Figure 96 Igelstaverket in Södertälje (heidelbergcement.com)

8.1.1.1 Visitor notes from Nykvarnsterminalen

The following notes were made during a visit at Nykvarnsterminalen in January 2013:

The terminal is owned by the municipality but operated by the Swedish railway operator Green Cargo.

The majority of the incoming wood chips arrive with Innofreight containers by rail, from different wood chip terminals in Sweden, for example Stockarydsterminalen.

Figure 97 The railway yard at Nykvarnsterminalen (soderenergi.se)

Approximately 6 – 7 train sets arrive to the terminal per week.

During the visit, approximately 27 000 ton wood chips were stored in the terminal.

All wood chips are stored on the ground.

The fresh wood chips originate from dismembered three residues and the recycled wood originates from waste yards.

The wood chips have a density of about 320 – 330 kg per m3 and the recycled wood has a density of about 180 – 220 kg per m3.

The wood chips are transported by road (operated by FORIA) from Nykvarnsterminalen to Igelstaverket in Södertälje, a distance of approximately 10 km. For these transports, the trucks are loaded with up to 40 ton biomass, which is loaded by a front loader, a Volvo L120, operated by the driver. With this arrangement there is no need for an extra driver of the front loader and the whole loading process takes 8-10 minutes. The truck drivers appreciate that they can load the truck by themselves, as they can decide where to put the cargo. There is also less damage to the trucks when the drivers are fully responsible for the loading process.

In the Nykvarn terminal Green Cargo has a 33 ton Innofreight forklift truck with rotating forks, which are used to discharge the containers. This truck is the only handling equipment available for unloading of wood chips in Innofreight containers. However, due to good technical service from Cargotec, which has delivered the truck (Kalmar truck), the terminal has not been exposed to any production losses since the start in 2009.

Figure 98 Unloading of an Innofreight container at Nykvarnsterminalen (MariTerm)

The Innofreight truck is operated by FORIA and they have noticed that the existing truck wears out quickly due to high utilization. As a consequence, they would prefer to have a truck with a capacity of 37 ton instead.

The forklift truck driver is very flexible. When the train set arrives, he unloads the Innofreight containers and discharges the wood chips. Later, he arranges the chips into stacks. Prior to the train arrival, he has contact with the train drivers in order to get information about expected delays.

In addition to the forklift truck driver, one person is employed for checking the moisture content in the biomass stored in the terminal. During winter, one additional person is required to clean the railway wagons from excessive wood chips and snow between the container slots.

During summer, it takes about 4 hours to unload a whole train set with 66 Innofreight containers. During winter the time is increased to 6 hours since more work is required. One issue during winter time is that the wood chips could be frozen in the bottom layer of the container, which requires shaking in order to release these layers. If this isn't done, the frozen layer will increase for every transport, which results in bad utilization of the container.

The wood chips start to fall out when the container is rotated 90 degrees and some quantities fall out first at 180 degrees. The remaining quantities require shaking and in some cases there are still layers left which cannot be released by this method (mainly during winter).

Figure 99 Excessive wood chips and snow between Innofreight containers on a railway wagon (MariTerm)

Frozen wood chip layers and the forklift rotator are the main disadvantages with the Innofreight container concept, but these disadvantages are considered to be of minor importance and overall the system works very well.

In some cases, Igelstaverket is supplied with biomass delivered by ships. Due to limited storage capacities at Igelstaverket, some quantities are transported to Nykvarnsterminalen. Since the boilers in Igelstaverket are configured for certain fuel qualities, some quantities use to be transported between Igelstaverket and Nykvarnsterminalen in order to have right fuels at the plant.

Transports with intermodal cargo transport units between Nykvarnsterminalen and Igelstaverket are not necessary at the moment since the wood chip loading is quick and easy and therefore not considered to be a problem.

To some plants in Stockholm, wood chips are transported from Sveg in common 20 ft. containers. These units are loaded by having the container standing on its short side, with the doors upwards. The container is discharged by backward tipping when placed on a trailer. The containers are transported by rail to Stockholm for storage and to the plant by road. No problems with icing have been noticed since the container is closed, which let the chips remain dry. If the container isn't fully weatherproof, some problems with icing may occur.

To date, there are no suitable cargoes for return transports.

Short railway transports exist, for example between Laxå and Eskilstuna, a distance of about 150 km.

An SG wagon with 4 axes can load 70 ton on a railway track in category D. These wagons are able to carry 3 Innofreight containers. Each container has a volume capacity of 45 m3, which equals a weight of 43 ton per wagon with a density of 320 kg per cubic metre. Each container has a tare weight of approximately 3 ton, which gives a total payload of 52 ton per wagon. With 22 wagons in a train set, the total weight amounts to 1 600 ton, with a tare weight for the wagons of 20 ton each.

8.1.1.2 Conclusions of the Nykvarn concept

Nykvarnsterminalen seems to have a relatively high efficiency rate with access to an in-house railway connection, optimized manning, high turnover and large storage capacities. It is, however, important to notice that the Nykvarn concept isn't an intermodal transport solution since it utilizes cargo transport units which cannot be used for road transports. The wood chips are loaded into WoodTainer XXL units and transported by rail to Nykvarnsterminalen from another biofuel terminal in Sweden. The units are then unloaded from the train and the wood chips discharged to the ground. From there, the wood chips are loaded to a road vehicle which is dedicated to biofuel transports. In this concept, several cargo transport units are engaged in different parts of the transport, requiring intermediate reloading of cargo. Such concepts are considered as multimodal transport solutions since several modes of transports are involved, each utilizing their own cargo transport units.

The WoodTainer XXL concept seems to work very well and the transport operator is satisfied with the technology so far. The discharging process of the WoodTainer XXL is fast and easy, which is a great benefit that keeps up the efficiency rate. Also the reloading process of wood chips into the road vehicles is efficient due to high capacity front wheel loaders. These aspects combined contribute to a good transport solution that is beneficial for the biofuel sector in this region.

8.2 Case study – Göteborg Energi, Sävenäs

In the BIOSUN project, a case study has been performed for supplying Göteborg Energi's plant in Sävenäs, Gothenburg, with 68% of their weekly demand of 6 440 ton wood chips during peak season by intermodal transports. The biofuel is supplied partly from the area around Stockaryd (60%) and partly from the area around Insjön (40%).

The distance between Stockaryd and Sävenäs is approximately 210 km and the distance from Insjön is approximately 460 km.

Figure 100 Transport pattern from Insjön and Stockaryd

The wood chips are made from unprocessed biomass at site in the forest. The biofuel is assumed to have a density of 0.29 ton/m^3.

This chapter contains a comparison of different intermodal cargo transport units' capability of transporting the biofuel in an intermodal transport chain, from the forest to the terminal by road and then from the terminal to the plant by rail.

8.3 Cargo transport unit capacities for road transports

To compare the capacities of different cargo transport units during the road transport, from the chipping site to the rail terminal, the number of vehicles needed to supply 68% of the plants weekly demand to the terminal has been calculated. In both Stockaryd and Insjön, the chips are collected from within a 40 km radius.

It has been assumed that each vehicle can make 3 round trips each day, 6 days a week. This of course depends heavily on the accessibility of the collecting site for the biofuel as well as the capacity of the wood chipping equipment at the site.

8.3.1 Current Swedish road regulations

The cargo transport unit capacities during road transport in the first table below, are calculated based on Swedish road regulations allowing a length of 25.25 metres and a maximum weight of 60 ton, depending on the distance between the first and last axle.

CTU	Units	Volume	Cargo Weight	Tare	Vehicle weight	Gross weight	Vehicles
	pcs	m^3	ton	ton	ton	ton	pcs
Container							
20 ft.	3	99	29	6,9	20	56	9
20 ft. ”High cube”	3	112	33	7,5	20	60	8
WoodTainer XXL[2]	2[1]	92	27	5,8	15,5	48	10
WoodTainer XXXL[2]	2[1]	116	34	6,2	15,5	55	8
20 ft. InnoFold F20	2[1]	82	24	5,8	15,5	45	11
40 ft.	1	64	19	3,7	15,5	38	14
40 ft. ”High cube”	1	76	22	4,0	15,5	42	12
45 ft. Pallet wide	1	86	25	4,6	15,5	45	10
Roll-off container							
20 ft. standard	3	105	30	8,9	20	59	9
Flis Elit 38 ISO	2[1]	76	22	5,6	15,5	43	12
Opticont Allround	3	117	34	6,5	20	60	8
Opticont FlisMax	2[1]	90	26	4,0	15,5	46	10
Econt	2[1]	80	23	5,6	15,5	44	11

Swap-body

A1212	1	74	21	4,4	15,5	41	12
A1250	1	76	22	4,5	15,5	42	12
A1360	1	80	23	4,9	15,5	44	11
C715	2	86	25	4,8	20	50	10
C745	2	90	26	5,0	20	51	10
C782	2	100	29	5,2	20	54	9

Trailer

EU-semitrailer	1	90	26	7,5	8,5	42	10

Table 18 Number of vehicles for present regulations

1. *The number of cargo transport units per vehicle is limited by the weight restrictions rather than the length restrictions for road vehicles.*
2. *The cargo transport unit is wider than the Swedish road regulations allow and a special permit would be required.*

For many of the purpose built containers, their superior volume cannot be taken into advantage since the weight restrictions for roads, rather than length restrictions, limits the number of cargo transport units to be carried on each vehicle. For that reason, standard 20 ft. containers are competitive for this part of the transport.

It must further be noted that, due to their width, WoodTainer containers cannot be used on road without a special permit. Since the collecting sites for the biofuel vary, it is questionable if such permit can be sought and cannot be used for the transport in this case study.

40 ft. containers and A-type swap-bodies have the poorest capacities among the compared cargo transport units and require the greatest number of vehicles to be employed to transport the units to the terminal. All swap-bodies have the advantage that they, without the need of trucks or heavy onboard equipment, can be discharged at the chipping site and filled while the vehicle collects empty units at the terminal. This might be helpful to improve efficiency, depending on the capacity of the wood chipper.

8.3.2 Possible future heavy road trains

In the table below, capacities have been calculated with Swedish road restrictions applying to trial vehicles[16] allowing a length of 30 metres and a maximum weight of 90 ton.

[16] ETT – Modulsystem för skogstransporter

CTU	Units pcs	Volume m^3	Cargo Weight ton	Tare ton	Vehicle weight ton	Gross weight ton	Vehicles pcs
Container							
20 ft.	4	132	38	9	20	67	7
20 ft. ”High cube”	4	150	43	10	20	73	6
WoodTainer XXL	3[2]	138[1]	40	8,7	20	69	7[1,2]
WoodTainer XXXL	3[2]	174[1]	50	9,3	20	80	5[1,2]
20 ft. InnoFold F20	4	164	48	11,6	20	79	6
40 ft.	2	128	37	7,4	15,5	60	7
40 ft. ”High cube”	2	153	44	8,04	15,5	68	6
45 ft. Pallet wide	2	172	50	9,18	15,5	75	5
Roll-off container							
20 ft. standard	4	140	41	12	20	72	7
Flis Elit 38 ISO	4	152	44	11	20	75	6
Opticont Allround	4	156	45	8,6	20	74	6
Opticont FlisMax	4	180	52	7,92	20	80	5
Econt	4	160	46	11,2	20	78	6
Swap-body							
A1212	2	148	43	8,8	15,5	67	6
A1250	2	152	44	9	15,5	69	6
A1360	2	160	46	9,8	15,5	72	6
C715	3	129	37	7,2	20	65	7
C745	3	135	39	7,5	20	67	7
C782	3	150	44	7,8	20	71	6
Trailer							
EU-semitrailer	2	180	52	15	8,5	76	5

Table 19 Number of vehicles in heavy road trains

1. *The number of cargo transport units per vehicle is limited by the weight restrictions rather than the length restrictions for road vehicles.*
2. *The cargo transport unit is wider than the Swedish road regulations allow and a special permit would be required.*

When extended vehicles are allowed, longer units such as 40 or 45 ft. containers, semitrailers and A-type swap-bodies become more competitive and there is over all less differences between the cargo transport unit concepts. Semitrailers and 45 ft. pallet wide containers are among the most efficient in this comparison.

For this type of road trains, accessibility of narrow forest roads or manoeuvring at the collecting site might provide limitations. In such cases, it might be useful to have a vehicle set up which allows for one or more units to be disconnected and withheld at an intermediate site while the remaining units are filled. The vehicle set up must then allow for the units to be exchanged and the withheld unit filled before they all hitched up and hauled to the terminal.

8.4 Cargo transport unit capacities for rail transports

A train schedule with 3 weekly arrivals from Stockaryd and 2 from Insjön has been set up for the case study. A detailed schedule is available in the Appendix A.

In the table below, both the required number of train arrivals per week to provide 68% of the fuel demand as well as the maximum capacity for delivery with 5 trains per week have been calculated when using different intermodal cargo transport units. For each unit, the most favourable railway waggon with a maximum train length of 630 meters has been used in the comparison. Descriptions of common waggon types for intermodal transports are found in chapter 3.

Most of the railway network between the destinations has the Swedish C-loading gauge. However, the track between Stockaryd and Nässjö is only class A and some unit and waggon combinations are not possible in practice. Even so, these combinations have been included in the tables for 126espectson, but cannot be recommended in this particular case study.

CTU	Volume m^3 / CTU	Waggon	CTU/ waggon pcs	Trains/ week[4] pcs	Capacity of 5 trains /week ton	Percent of demand[5] %
Container						
20 ft.	33	Sgns	3	4,9	4450	69%
		Lgns 2x20’	2	5,2	4211	65%
20 ft. ”High cube”	37	Sgns	3	4,4	5043	78%
		Lgns 2x20’	2	4,6	4772	74%
WoodTainer XXL	46	Sgns	3	3,5	6203	96%
		Lgns 2x20’	2	3,7	5870	91%
WoodTainer XXXL	58	Sgns [1, 6]	3	2,8	7821	121%
20 ft. InnoFold F20	41	Sgns	3	4,0	5529	86%
		Lgns 2x20’	2	4,2	5232	81%
40 ft.	64	Lgjns	1	6,8	3248	50%
40 ft. ”High cube”	76	Lgjns	1	5,7	3877	60%
45 ft. Pallet wide	86	Lgjns	1	5,0	4365	68%
Roll-off container						
20 ft. Standard	35	Sgnss-v [2]	3	5,1	4263	66%
Flis Elit 38 ISO	38	Sgnss-v[6]	3	4,7	4628	72%
		Sgns	2	6,4	3416	53%
Opticont Allround	39	Sgnss-v [2, 6]	3	4,6	4750	74%
Opticont FlisMax	45	Sgnss-v [2, 6]	3	4,0	5481	85%
Econt	40	Sgnss-v[6]	3	4,5	4872	76%
		Sgns	3	6,1	3596	56%
Swap-body						
A1212	74	Sdggmrs[3]	2	6,0	3648	57%
A1250	76	Sdggmrs[3]	2	5,9	3747	58%
A1360	80	Sdggmrs[3]	2	5,6	3944	61%
C715	43	Sdggmrs[3]	4	5,2	4240	66%
C745	45	Sdggmrs[3]	4	4,9	4437	69%
C782	50	Sdggmrs[3]	4	4,5	4930	77%
Trailer						
EU-semitrailer	90	Sdggmrs[3]	2	4,9	4437	69%

Table 20 Cargo transport unit capacities for rail transports

1. *Could not be transported on the Lgns waggon due to weight restrictions.*
2. *Low utilization on the Lgs-x waggon due to weight restrictions. No corner castings. Requires the very rare Sgnss-v waggon to be used.*
3. *Waggon type is Sdggmrs (T2000)*

4. *Number of train arrivals required per week for supplying 68% of the demand, based on a maximum train length of 630 m.*
5. *Percent of the total estimated demand of 6 440 ton that can be supplied by 5 train arrivals per week*
6. *Does not fit within the class A loading gauge*

Among the containers, the 20 ft. units achieved a higher capacity than 40 ft. units due to the fact that they can be transported on the Lgns and Sgns waggons, which can carry more units per meter. Utilizing the width of the loading gauge, the WoodTainer units achieved the highest capacity for the rail transport in this case study. However, due to their heavy weight at full load, the choice of waggons is limited for Woodtainer XXXL. Also, it does not fit within the class A loading gauge and cannot be used for the transport.

In case of roll-off containers, these are ultimately transported on waggons which are equipped with a swinging chassis which allow the cargo transport units to be loaded and unloaded directly to and from the road vehicle without lifting. However, the most common type, the Lgs-x waggon, have a cargo capacity of only 22.7 tons and instead the very rare Sgnss-v waggon have to be used for this function. Additionally, none of the purpose built roll-off containers fit within the class A loading gauge when transported on roll-off container waggons. Alternatively, some of the roll-off containers are equipped with corner castings and can be transported on container waggons, but the capacity for this system becomes very low and the unique function of shifting transport mode without lifting is lost.

Swap bodies are designed to meet the restricted dimensions on European road and railway systems. Especially the C-type swap-bodies have a capacity that can match many of the purpose built wood chip cargo transport units during rail transports.

It should further be noted that some of the units do not make it possible to supply 68% of the demanded biofuel with 5 train arrivals per week. They are thus not suitable for the transport in this case study.

8.5 Road transport the whole distance

For comparison, the number of road vehicles needed for supplying 68% as well as 100% of the demand of 6 440 tons of biofuel has been calculated in the table below.

Vehicle	Volume	Weight	Vehicles required for 68% of demand			Vehicles required for 100% of demand		
	m^3	ton	*Stockaryd*	*Insjön*	***Total***	*Stockaryd*	*Insjön*	***Total***
60 ton – Standard	135	39,2	12	15	**27**	17	22	**39**
74 ton	165	47,9	10	13	**23**	14	18	**32**
90 ton	200	58,0	8	11	**19**	12	15	**27**

Table 21 Number of vehicles for pure road transports

The required number of vehicles has been based on the assumption that vehicles from Stockaryd can make 6 roundtrips per week and vehicles from Insjön can make 3 round trips per week.

Calculations have been made for the present capabilities of 60 ton vehicles but also for heavier road trains, with a gross weight of 74 and 90 ton 129es-pecttively, as these are currently being tested and evaluated.[17]

8.6 Conclusions of case study

It can be concluded that many of the purpose built cargo transport units, especially the 20 ft. container types, have a very high capacity for parts of the transport, but due to weight and dimensional restrictions are not suitable for the road transport.

The roll-off containers all require to be transported on the Sgnss-v waggon to meet the minimum requirement for supplying 68% of the demanded biofuel, e.g. 4 380 ton per week. Unfortunately, this waggon is very rare and Green Cargo has only one single unit in their fleet.

Furthermore, the cargo transport units' suitability to accommodate a return cargo should also be taken into account, and arguably it would be easier to find a higher utilization level when using standard units, both for the return trip and also for the off-peak season.

Among the standard containers, the 20 ft. high cube unit provides the highest capacity overall. Although an open top version must be used, this unit type is reasonably available. It may also be applied for other services to achieve a good whole year utilization.

The swap-bodies of A-type provide a poor capacity for both the rail and the road transport under the current length restrictions and the C-type units should be chosen instead. Especially the longer C782 is favourable from a capacity perspective.

If road regulations are altered to allow longer road trains, the semitrailer could be a viable option. For purposes of loading and emptying, purpose built units would have to be used. These could be based on the design of current wood chip trucks. Considering the possible difficulties of reaching inaccessible collecting sites in the forest, these could be a flexible solution, since they can be disconnected and one unit at a time could be delivered for filling.

[17] ETT – Modulsystem för skogstransporter

9 Conclusions

This study was aimed to analyze different intermodal concepts for transports of wood biofuels and to identify areas which could have a negative impact on the transport efficiency. What has been shown in this report is that there are a lot of different cargo transport units available on the market today, each one of them with both benefits and drawbacks. Several different concepts have been identified but none of them has been considered as an optimal solution for intermodal transports of wood biofuels.

It has been concluded that it's not possible to identify deficiencies which are generally applicable for all types of cargo transport units, except for the bad weight and volume compatibility between road and railway transports. The fact that the maximum allowed width and height dimensions are badly harmonized between road and rail is a well-known issue, which has engaged transport developers for a long period of time. Without a better harmonization it is difficult to find a solution which isn't considered as a compromise between different aspects. To find a design of an intermodal cargo transport unit which utilizes the maximum space in both road and rail transports, without reloading of the cargo, has not been possible within this project.

Since it is difficult to change the dimensions of the intermodal cargo transport units without affecting the compatibility with either road or railway transports, one solution could be to introduce legislative changes. It could, for example, be allowed to increase the maximum length for road carriers from 25.25 m to 30 m, which would give space for one additional cargo transport unit. Another legislative change could be to give permanent allowance for road carriers transporting biofuels, to have a maximum width of 2.90 m instead of 2.60 m. This width would allow transports of WoodTainer XXLs, which are commonly used for railway transports of biofuels. Since these units have shown to be very effective, especially in terms of unloading, it would be beneficial to allow them to be carried on road carriers without any restrictions.

Transports of wood biofuels are cost-sensitive due to low cargo values. This is an aspect which has a great impact on the ability to use dedicated transport solutions. One aspect of dedicated transport systems is that they could give rise to costs for positioning of empty carriers, if not engaged in a closed environment where all equipment remains in the same network. It could, for example, be more difficult to find a railway wagon intended for transports of roll-off containers than finding a wagon suitable for standard containers. If a railway wagon for roll-off containers isn't available nearby, there's a cost for positioning between these locations. Even if transports of roll-off containers could have a better volume utilization than containers, the additional costs and planning requirements could make such concepts less compatible in an overall perspective. There's a great benefit to use concepts with high availability on the market.

Intermodality has no value of its own, it's relevant only when the intermodal transport solution has great advantages over mono or multimodal concepts. Operators in the biofuel industry have concluded that reloading of wood biofuels between different modes of transport isn't considered as a problem since the reloading cost is relatively low compared to reloading of unified cargoes. The reloading process can also be executed fast and easy, especially in terminals with front wheel loaders, for which a complete reloading takes just a couple of minutes. Due to the volume and weight incompatibility between road and railway transports, it is beneficial to have an intermediate reloading process since it allows full volume and weight utilization in both modes of transport.

It has been shown in practical tests that freezing of wood chips in containers could be a problem for winter time transports. The moisture content is a crucial factor and it was concluded that moisture levels above 38% are likely to result in freezing issues and that moisture levels below 31% aren't likely to result in such issues. On the opposite side moisture levels above 58% led to 100% freezing. It was also shown that anti-adherent paint can reduce these problems. An anti-adherent paint used on icebreaker hulls showed a significant reduction in adherent of wood chips after a number of inclination tests. To achieve these results a vibrating shock had to be added to the boxes since no release could be observed for inclinations up to 180°, for moisture levels above 38%. This means that vibration is required to initiate a release.

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http://www.tillvaxtverket.se/euprogram/huvudmeny/programperiod20072013/resultat/godaexempelartiklar/biobransleterminalenskapacitetharokatvasentligt.5.5a5c099513972cd7fea323c4.html

Appendix A – Case study, Göteborg Energi, Sävenäs

Sävenäs-Stockaryd

3 gånger i veckan

Avstånd	262	km enkel väg	
Sävenäs-Borlänge/Insjön	448	km enkel väg	

2 gånger i veckan

Totalt trafik 5 dagar i veckan — Kommer även testa att bara köra Sävenäs 3 gånger i veckan. Borde öppna fler möjligheter för returflöden då.

26 veckor om året trafik

Tåg:			
Lok:	Rd		
Vagnar:	Sgns		
Antal vagnar:	22	st	
Lastbärare	Innofreight XXL		
Antal lastbärare	66	per avgång	
Bränsle:	Grotflis		vanligaste bränslet, eventuellt sågverksprodukter från Dalarna.
Flisning:	Skogen		
Energi per tåg	2 317	mwh	utifrån grotflis
Energi per vecka	11 585	mwh	Göteborg Energi uppger att de vid full drift gör slut på ca 17GWh per vecka.
Vikt per tåg	877,8	ton netto, lastad vikt	
Totalvikt tåg	1 584	ton	
Tåglängd	447	meter	
Forsling till terminal:	40	km	Stockaryd uppger i intervju ca 3-4 mil inforslingsavstånd.
Fordon:	Containerflisbil, 40m3 container		
Omlastning	Hjullastare		
Lastning av ett tåg	4	timmar	Respondenterna uppger 4-5 timmar.
Lossning	Innofreighttruck		

Direkt på anläggning i Sävenäs

OBS! i grundcaset bortses från Sävenäs korta spår och att flera växlingar och rangeringar skulle krävas.
Detta kommer att inkluderas senare, men för unikt att inkludera i grundcaset då resultaten skulle bli omöjliga att generalisera för andra upplägg.

Lossning av ett tåg:	4	timmar	enligt vår enkät.
Växling			
Stockaryd	El med fjärrloket, Rd		
Sävenäs	Diesellok, T44		
Insjön	Diesellok, T44		

Sävenäs öppet för lossning

06-22	alla dagar	Till för några veckor sedan fick de inte lossa helger och röda dagar, men det får dom nu. Ligger i ett bostadsområde så helger och sena kvällar är bra om det kan undvikas.

Tidtabell (grov), 5 dagar

Dag	Ort	Omlopp	Aktivitet	Klockslag	Kommentar
Söndag	Stockaryd	1	Lastning	Eftermiddag	Ingen anledning att lasta på natten om tåget ändå är tillgängligt.
Söndag	Stockaryd	1	Avgång	natt	ca 5 timmar körning
Måndag	Sävenäs	1	Ankomst	tidig morgon	Sävenäs lager är i princip tomt på måndag morgon så viktigt att ett tåg kommer in då. Bör undvika lossningar på helgerna även om det är tillåtet numera. Om det ger bättre utnyttjande av tåget är det dock ok att skjuta fram tåget till måndag eftermiddag och anta att de istället får ta in mer bilar på morgonen.
Måndag	Sävenäs	1	Lossning	Klar innan lunch	
Måndag	Sävenäs	2	Avgång	Eftermiddag	ca 8,5 timmar körning
Tisdag	Insjön	2	ankomst	kväll/natt	
Tisdag	Insjön	2	lastning	tidig morgon	4 timmar
Tisdag	Insjön	2	avgång	innan lunch	ca 9-10 tiden
Tisdag	Sävenäs	2	ankomst	sen eftermiddag	ca 18 tiden
Tisdag	Sävenäs	2	lossning	kväll	får lossa fram till 22.
Tisdag	Sävenäs	3	avgång	natt	
Onsdag	Stockaryd	3	Ankomst	morgon	
Onsdag	Stockaryd	3	Lastning	förmiddag	klar ca 10 tiden
Onsdag	Stockaryd	3	Avgång	innan lunch	
onsdag	Sävenäs	3	ankomst	eftermiddag	ca 15 tiden
Onsdag	Sävenäs	3	Lossning	eftermiddag/kväll	får lossa fram till 22.
Onsdag	Sävenäs	4	Avgång	kväll	ca 20 tiden
Torsdag	Insjön	4	Ankomst	tidig morgon	ca 5-6 tiden
Torsdag	Insjön	4	Lastning	förmiddag	
Torsdag	Insjön	4	avgång	innan lunch	ca 10 tiden
Torsdag	Sävenäs	4	ankomst	kväll	ca 18 tiden
Torsdag	Sävenäs	4	lossning	kväll	får lossa fram till 22.
Torsdag	Sävenäs	5	avgång	natt	
Fredag	Stockaryd	5	ankomst	tidig morgon	
Fredag	Stockaryd	5	lastning	förmiddag	
Fredag	Stockaryd	5	avgång	lunch	
Fredag	Sävenäs	5	Ankomst	sen eftermiddag	
Fredag	Sävenäs	5	Lossning	kväll	
Fredag	Sävenäs	1	Avgång		tidigast avgång fredag kväll, senast avgång söndag morgon.
Lördag/söndag	Tåget är tillgängligt för annat. Antingen parkerat på Sävenäs, Stockaryd eller annan plats, eller kör för annat värmeverk/uppdrag. Går även att flytta om så att de "lediga" dagarna hamnar mitt i veckan.				

Tidtabell (grov), 3 dagar

Söndag	Stockaryd	1	Lastning	Eftermiddag	Ingen anledning att lasta på natten om tåget ändå är tillgängligt.
Söndag	Stockaryd	1	Avgång	natt	ca 5 timmar körning
Måndag	Sävenäs	1	Ankomst	tidig morgon	Sävenäs lager är i princip tomt på måndag morgon så viktigt att ett tåg kommer in då. Bör undvika lossningar på helgerna även om det är tillåtet numera. Om det ger bättre utnyttjande av tåget är det dock ok att skjuta fram tåget till måndag eftermiddag och anta att de istället får ta in mer bilar på morgonen.
Måndag	Sävenäs	1	Lossning	Klar innan lunch	
Måndag	Sävenäs	2	Avgång		tidigast måndag eftermiddag, senast tisdag natt
Tisdag					
Tisdag	Tåget är tillgängligt för annat. Antingen parkerat på Sävenäs, Stockaryd eller annan plats, eller kör för annat värmeverk/uppdrag.				
Tisdag					
Onsdag	Stockaryd	2	Ankomst	morgon	
Onsdag	Stockaryd	2	Lastning	förmiddag	klar ca 10 tiden
Onsdag	Stockaryd	2	Avgång	lunch	
onsdag	Sävenäs	2	ankomst	eftermiddag	ca 16-17 tiden
Onsdag	Sävenäs	2	Lossning	eftermiddag/kväll	får lossa fram till 22.
Onsdag	Sävenäs	3	Avgång		tidigast onsdag kväll, senast torsdag natt
Torsdag					
Torsdag	Tåget är tillgängligt för annat. Antingen parkerat på Sävenäs, Stockaryd eller annan plats, eller kör för annat värmeverk/uppdrag.				
Torsdag					
Fredag	Stockaryd	3	ankomst	morgon	
Fredag	Stockaryd	3	lastning	förmiddag	klar ca 10 tiden
Fredag	Stockaryd	3	avgång	lunch	
Fredag	Sävenäs	3	Ankomst	eftermiddag	ca 16-17 tiden
Fredag	Sävenäs	3	Lossning	eftermiddag/kväll	får lossa fram till 22.
Fredag	Sävenäs	1	Avgång		tidigast fredag kväll, senast avgång söndag morgon
Lördag/Söndag	Tåget är tillgängligt för annat. Antingen parkerat på Sävenäs, Stockaryd eller annan plats, eller kör för annat värmeverk/uppdrag.				
	Går även att flytta om så att de ”lediga” dagarna hamnar mitt i veckan.				

Appendix B – Practical tests with frozen wood chips

The following wood chip qualities were used during the tests. The moisture content represents the original condition in which the chips were delivered.

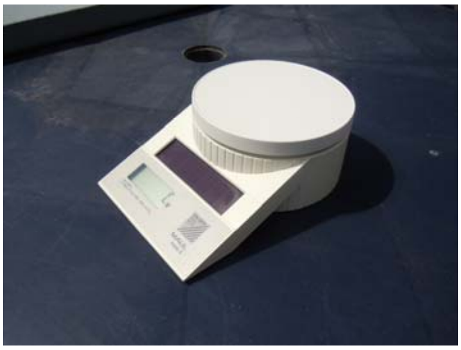
NO. 1 – TIMBER WOOD CHIPS	
Moisture content	49%
Weight	345 kg/m3
Density for dry chips	175 kg/m3

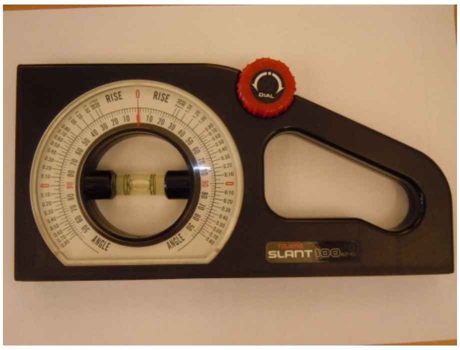
NO. 2 – GROT WOOD CHIPS	
Moisture content	28%
Weight	207 kg/m3
Density for dry chips	150 kg/m3

NO. 3 – STUMP WOOD CHIPS	
Moisture content	34%
Weight	205 kg/m3
Density for dry chips	135 kg/m3

The following equipment was used during the tests.

DATA OF EQUIPMENT		
Plastic box, 2 liter	Tare = 54 g.	

Letter scale	Precision 0-2000 g = 2 g	 
Freeze	-18°C	
Container 1	Standard paint used on ship hulls	

Container 2	Anti-adhesive paint used on icebreaker hulls	
Hammer	Weight=708 g	
Inclinometer	Tajima slant100	

TEST No. 1 – Timber wood chips	
Weight 1 liter 766-54=712	712 g / 2 = 356 g
Moisture content x+175=356 x=181 181/356=0.51	51%
Processing	no
Comment	moist

RESULTS TEST NO. 1

Picture showing the results of test no 1. The remaining quantities were estimated to 30% in container 1 (red) and to <5% in container no. 2 (grey) after a 180° inclination and an added hammer shock.

RESULTS CONTAINER 1 – STANDARD PAINT	
	
Load before freezing	Load after freezing
	
Load during inclination <90°	Load at 90° inclination
no movements	no movements
	
Load during inclination >90°	Load during inclination <180°
no movements	no movements
RESULTS AFTER ONE HAMMER SHOCK	
	
wood chips left in bottom, approx. 30%	

<table>
<tr><th colspan="2">RESULTS CONTAINER 2 – ICEBREAKER PAINT</th></tr>
<tr><td>
</td><td></td></tr>
<tr><td>Load before freezing</td><td>Load after freezing</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Load during inclination <90°</td><td>Load at 90° inclination</td></tr>
<tr><td>no movements</td><td>no movements</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Load during inclination >90°</td><td>Load during inclination <180°</td></tr>
<tr><td>no movements</td><td>no movements</td></tr>
<tr><th colspan="2">RESULTS AFTER ONE HAMMER SHOCK</th></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">wood chips left in bottom, approx. <5%</td></tr>
</table>

TEST No. 2 – Timber wood chips	
Weight 1 liter 814-54=760	760 g / 2 = 380 g
Moisture content x+175=380 x=205 205/380=0.54	54%
Processing	showered with water in intervals during 1 hour
Comment	wet

RESULTS TEST NO. 2

Picture showing the results of test no 2. The remaining quantities were estimated to 50% in container 1 (red) and to 20% in container no. 2 (grey) after a 180° inclination and an added hammer shock.

RESULTS CONTAINER 1 – STANDARD PAINT

Load before freezing

Load after freezing

Load during inclination <90°

no movements

Load at 90° inclination

no movements

Load during inclination >90°

no movements

Load during inclination <180°

no movements

RESULTS AFTER ONE HAMMER SHOCK

wood chips left in bottom, approx. 50%

RESULTS CONTAINER 2 – ICEBREAKER PAINT

Load before freezing

Load after freezing

Load during inclination <90°

no movements

Load at 90° inclination

no movements

Load during inclination >90°

no movements

Load during inclination <180°

no movements

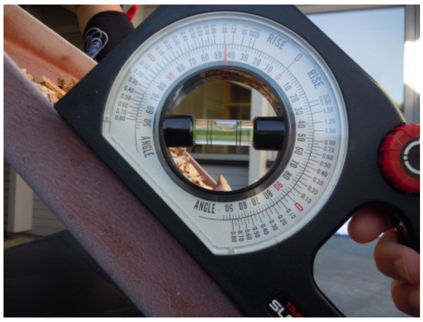
RESULTS AFTER ONE HAMMER SHOCK

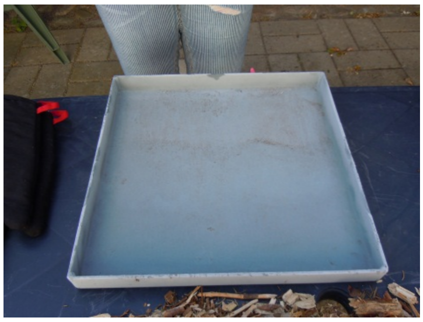
wood chips left in bottom, approx. 20%

TEST No. 3 – Grot wood chips	
Weight 1 liter 490-54=436	436 g / 2 = 218 g
Moisture content x+150=218 x=68 68/218=0.31	31%
Processing	no
Comment	dry

RESULTS TEST NO. 3

Picture showing the results of test no 3. The remaining quantities were 0% in container 1 (red) and 0% in container no. 2 (grey) after a 45° inclination.

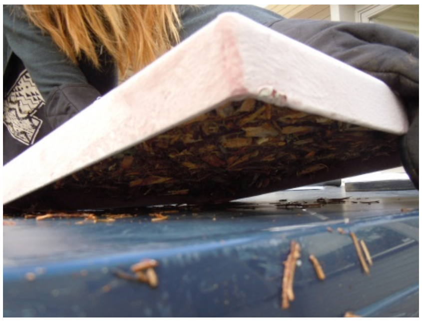
<table>
<tr><th colspan="2">RESULTS CONTAINER 1 – STANDARD PAINT</th></tr>
<tr><td>
</td><td></td></tr>
<tr><td>Load before freezing</td><td>Load after freezing</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Load during inclination at 45°</td></tr>
<tr><td colspan="2">wood chips began to move</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Load during inclination at 90°</td></tr>
<tr><td colspan="2">clean surface</td></tr>
</table>

RESULTS CONTAINER 2 – ICEBREAKER PAINT	
	
Load before freezing	Load after freezing
	
Load during inclination at 45°	
wood chips began to move	
	
Load during inclination at 90°	Result after inclination
clean surface	

TEST No. 4 – Grot wood chips	
Weight 1 liter 618-54=564	564 g / 2 = 282 g
Moisture content x+150=282 x=132 132/282=0.47	47%
Processing	showered with water in intervals during 1 hour
Comment	wet

RESULTS TEST NO. 4

Picture showing the results of test no 4. The remaining quantities were estimated to 75% in container 1 (red) and to <10% in container no. 2 (grey) after a 180° inclination and an added hammer shock.

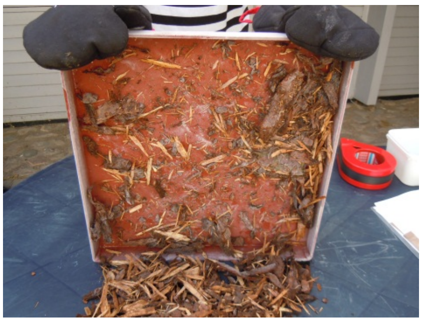
RESULTS CONTAINER 1 – STANDARD PAINT	
	
Load before freezing	Load after freezing
	
Load during inclination <90°	Load at 90° inclination
no movements	no movements
	
Load during inclination >90°	Load during inclination <180°
no movements	no movements
RESULTS AFTER ONE HAMMER SHOCK	
	
wood chips left in bottom, approx. 75%	

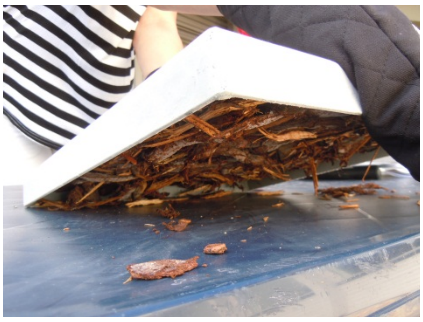
<table>
<tr><td colspan="2">RESULTS CONTAINER 2 – ICEBREAKER PAINT</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td>Load before freezing</td><td>Load after freezing</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Load during inclination <90°</td><td>Load at 90° inclination</td></tr>
<tr><td>no movements</td><td>no movements</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Load during inclination >90°</td><td>Load during inclination <180°</td></tr>
<tr><td>no movements</td><td>no movements</td></tr>
<tr><td colspan="2">RESULTS AFTER ONE HAMMER SHOCK</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">wood chips left in bottom, approx. <10%</td></tr>
</table>

TEST No. 5 – Stub wood chips	
Weight 1 liter 486-54=432	432 g / 2 = 216 g
Moisture content x+135=216 x=81 81/216=0.38	38%
Processing	no
Comment	slightly moist

RESULTS TEST NO. 5

Picture showing the results of test no 5. The remaining quantities were estimated to 40% in container 1 (red) and to 5% in container no. 2 (grey) after a 180° inclination and an added hammer shock.

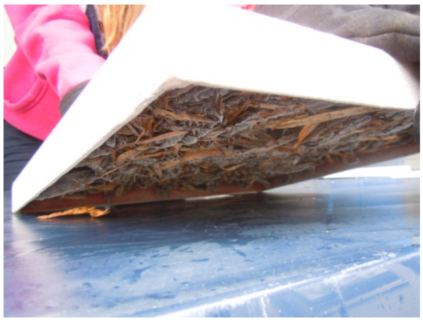
<table>
<tr><td colspan="2">RESULTS CONTAINER 1 – STANDARD PAINT</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td>Load before freezing</td><td>Load after freezing</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Load during inclination <90°</td><td>Load at 90° inclination</td></tr>
<tr><td>no movements</td><td>no movements</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Load during inclination >90°</td><td>Load during inclination <180°</td></tr>
<tr><td>no movements</td><td>no movements</td></tr>
<tr><td colspan="2">RESULTS AFTER ONE HAMMER SHOCK</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">wood chips left in bottom, approx. 40%</td></tr>
</table>

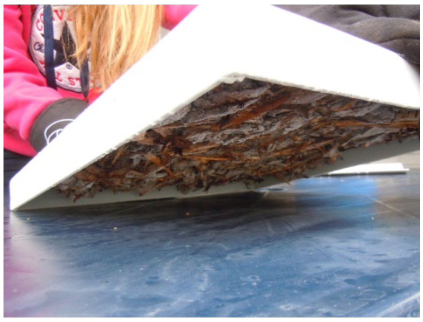
<table>
<tr><th colspan="2">RESULTS CONTAINER 2 – ICEBREAKER PAINT</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Load before freezing</td><td>Load after freezing</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Load during inclination <90°</td><td>Load at 90° inclination</td></tr>
<tr><td>no movements</td><td>no movements</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Load during inclination >90°</td><td>Load during inclination <180°</td></tr>
<tr><td>no movements</td><td>no movements</td></tr>
<tr><th colspan="2">RESULTS AFTER ONE HAMMER SHOCK</th></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">wood chips left in bottom, approx. 5%</td></tr>
</table>

TEST No. 6 – Stub wood chips	
Weight 1 liter 690-54=636	636 g / 2 = 318 g
Moisture content x+135=318 x=183 183/318=0.58	58%
Processing	showered with water in intervals during 1 hour
Comment	wet

RESULTS TEST NO. 6

Picture showing the results of test no 6. The remaining quantities were 100% in container 1 (red) and 100% in container no. 2 (grey) after a 180° inclination and an added hammer shock.

RESULTS CONTAINER 1 – STANDARD PAINT	
	
Load before freezing	Load after freezing
	
Load during inclination <90°	Load at 90° inclination
no movements	no movements
	
Load during inclination >90°	Load during inclination <180°
no movements	no movements
RESULTS AFTER ONE HAMMER SHOCK	
	
no movements	

RESULTS CONTAINER 2 – ICEBREAKER PAINT	
	
Load before freezing	Load after freezing
	
Load during inclination <90°	Load at 90° inclination
no movements	no movements
	
Load during inclination >90°	Load during inclination <180°
no movements	no movements
RESULTS AFTER ONE HAMMER SHOCK	
	
no movements	