Comparing the Environmental and Economic Impact of the CargoTube System with Road-based Transport

Stephan Wurst[1], Lukas Eschment[2], Thomas Schüning[2], Thomas Nobel[3], Heiko Duin[4], Walter Neu[2]

[1] BALance Technology Consulting GmbH, 28203 Bremen, Germany, stephan.wurst@bal.eu
[2] Institute of Hyperloop Technology, University of Applied Sciences Emden/Leer, 26723 Emden, Germany, lukas.eschment@hs-emden-leer.de
[3] to-be-now-logistics-research-gmbh, 28865 Lilienthal, Germany, nobel@tbnlr.de
[4] BIBA – Bremer Institut für Produktion und Logistik GmbH, 28359 Bremen, Germany, du@biba.uni-bremen.de

Abstract. CargoTube is a low-pressure tube transport (LPTT) solution aimed at zero-emission high-speed transport. In order to prove the feasibility of the solution a prototype is under development which should connect a LSP with an automotive plant. The Horizon 2020 project ePIcenter has defined the demonstrator in a cooperation project of multiple partners with different expertise in terms of Hyperloop technology, simulation and analysis of the impact. To support an investment decision, an analysis is planned that will investigate the environmental and economic impact of the CargoTube system in comparison with the current truck-based connection..

In order to evaluate the impact of the LPTT CargoTube connection, a Life Cycle Performance Assessment (LCPA) is carried out. It compares one or more future scenarios against a baseline scenario representing common practice. In the context of the CargoTube demonstrator, the analysis concentrates on a subset of available KPIs. The financial aspects are mainly covered by CAPEX, OPEX and NPV, while the environmental impact is represented by the GWP (Global Warming Potential) measured as CO_2 equivalent.

The paper will show the results of the analysis and the conclusions to be drawn for the demonstrator implementation.

.**Keywords:** Hyperloop, CargoTube, Sustainable Logistics Transport, Energy Efficient Transport, Environmental Impact, Life Cycle Performance Assessment

1 ePIcenter and the CargoTube System

1.1 Introduction to the ePIcenter Project

The ePIcenter project aims at developing and testing AI driven logistic software solutions, new transport technologies and supporting methodologies to increase the efficiency of global supply chains and reduce their environmental impact.

Main aspects are visibility and collaboration, making the supply chains or logistic processes more transparent through cyber secure data exchange and sharing, and optimisation, using new data and emerging technologies in a smart way, that can optimise the real life logistics and synchromodal planning processes end users are facing daily.

In combination, the work on these two themes will take a major step towards the Physical Internet concept and seamless sustainable global freight flows. The project delivers relevant applications, that can easily be transferred to other end-users. Taking into account emerging technologies (e.g. hyperloop, automated vehicles) and trade routes (Silk route, Arctic route) in the simulation modules, the project also prepares for the future and challenges ahead.

1.2 CargoTube in the ePIcenter context

The use case scenario of implementing hyperloop as a reliable transport system to deliver cargo to one of the major logistics hubs of the Wolfsburg VW plant design criteria are set according to the needs that are identified during a visit of the logistics hub inside of the manufacturing plant.

The transport of incoming material from a possible Logistic Service Park (LSP) in the WOB-Heinenkamp-area to the VW plant could happen e.g., via hyperloop, while the logistics centre itself is perfectly connected via the A39 to the road network. The hyperloop system would supply the "Logistics Hall 55" in time with necessary items while the complete offloading, storage and sorting is handled at the “LSP-Heinenkamp” site. A detailed description of the envisaged prototype is given in [1]. This paper concentrates on evaluating the environmental and economic impact of the demonstrator.

2 Assessing the Performance of the CargoTube demonstrator

2.1 The LCPA Method

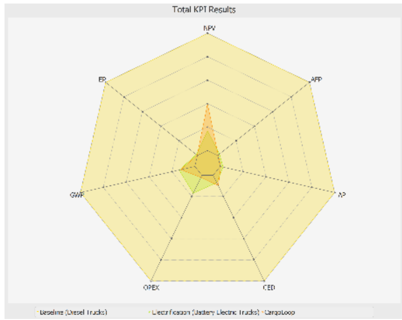
The Lifecycle Performance Assessment (LCPA) method can be used to analyse the environmental and economic performance of a product or system. The method typically compares one or more innovative solutions against a reference system (typically the commonly used solution that should be replaced by an innovative development. The LCPA tool implementing the method covers all lifecycle phases starting with the design and finishing with the recycling. The energy consumption is not only measured for system construction and operation but also for the fuel production.

Depending on the availability of information the LCPA model might be created with brief information first and can then be refined when detailed information becomes available during detail design and especially during operation. Therefore, an overview of the expected results may be generated with limited input while in later stages the expectations might be compared with the actual performance of the finished product.

The Key Performance Indicators with respect to the economic performance are Net Present Value (NPV), Operational Expenditures (OPEX) and Capital Expenditures (CAPEX). For the environmental performance, Acidification Potential (AP), Eutrophication Potential (EP), Aerosol Formation Potential (AFP) and Global Warming Potential (GWP). A detailed description of the method is given in [1].

2.2 Software Tool to carry out LCPA

The LCPA software tools implements the method and supports the entire LCPA process starting from model preparation over running the calculations to the result presentation. It has a builtin database for predefined elements (e.g. materials, energy converters fuels, and financial data) while the project related input data either will be imported from external applications such as LCA databases or simulation systems or will be entered manually. Once the scenarios have been defined, the LCPA calculation will be run, resulting in the KPI values for the entire life cycle determined by the model. The results will then either be visualized as development over time or as bar chart showing the total values. By analysing these charts, it can be determined which scenario performs best for the different KPIs. To get an overview of all KPIs, a spider web chart is provided that supports the decision of which scenario will overall the most promising one.



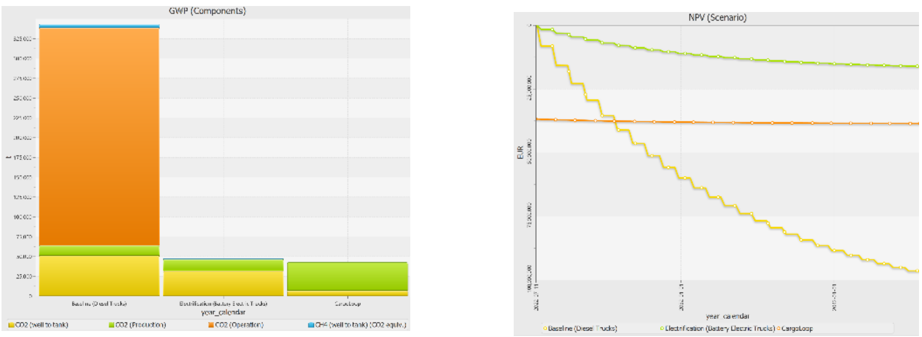


Fig. 1. Visualisations of LCPA results

3 Comparison of CargoTube and Truck-based solutions

3.1 Scenarios to be considered

The Hyperloop demonstrator will be compared against two alternative scenarios: The reference scenario is the transport by diesel trucks (as used today). A second scenario will be the transport by electric trucks. Although this scenario has not been realised yet it is likely that it will materialize itself in the next few years and will therefore be the actual competition of the Hyperloop. Actually, the transition has started by ordering the first battery-electric vehicles.

In the first step the LCPA model template has been implemented, containing the three scenarios and the input variables required to run the calculations. An example of the hyperloop scenario is shown in the following figure.

All scenarios consist of two main phases, construction and operation. The construction phase will mainly cover the investment effort needed to set up the different solutions. The operation phase comprises the transport, loading, unloading and maintenance activities and the financial effort and energy consumption to perform the transportation tasks. To reduce calculation time, the different activities are bundled per year which will result in an output that will be accurate on a yearly granularity. If more detailed results will be needed, the phase durations and repetition could be adjusted.

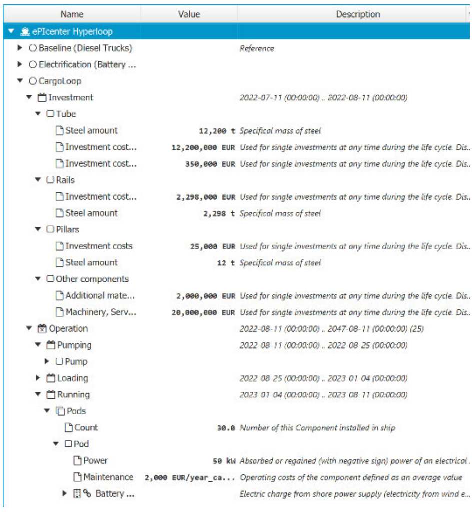


Fig. 2. LCPA model template

As the demonstrator evolves, the model will be refined in order to cover all necessary values. Input values for the Hyperloop will be taken from the simulation module for the variables used in both models. The data for the truck scenarios will be either retrieved from the Wolfsburg GVZ or, in case it is not available or incomplete, from comparable logistics enterprises.

3.2 The LCPA Model and the Input data

In autumn 2022 around 1,000 trucks/day delivered goods to the VW plant, a number still oppressed by the parts shortage. There are approx. 130 unloading points in the VW factory, with Hall 55 having the most incoming units. Therefore, the LCPA model is based on the assumption that the transport is carried out as a 1:1 connection between the logistics center and Hall 55. The following basic data characterize the current logistics processes in Hall 55:

- An average of 35 loading units (LU) per truck across all load carrier units
- Capacity/utilization of Hall 55 about truck deliveries: peak 140-150 trucks per day. An average of around 100 trucks/day in recent years.
- Further, the ePIcenter team was able to examine various location options for a possible logistics service park (LSP) in the "Wolfsburg-Heinenkamp" urban area. The LSP could be the starting point for supply chains using a hyperloop tube.
- Around 12,600 boxes must be transported each day.

- The CargoTube system is expected to have two tubes of a length of 12 km, one tube for each direction. The minimal inner diameter of the tube needs to be 1.65 m resulting in around 14,000 t of steel and 12,000 t of concrete for the floor inside the tube. Further steel and concrete are needed for the rail system and the pillars.
- The total volume within the two tubes is around 45,000 m3. The time for tube evacuation down to 10 mbar is around 3 days.
- Assuming a repressure time and automated unloading/loading time of one minute each result in a handling time of 4.2 minutes including the evacuation.
- The total travel time for a pod is 5.5 minutes including acceleration and braking.
- In full operation, this CargoTube system can handle 36 pods simultaneously.

The compared truck scenarios assume that an amount of 40 diesel or battery electric trucks are needed to fulfil the transport requirements. These trucks are typically leased and therefore frequently replaced, thus reducing degradation and maintenance costs.
For each scenario, the investment and the operational phase were modelled. The LCPA tool supports the enabling and disabling of model parts. It therefore allows consideration of either the full lifecycle (including the investment phase) or the operation phase only. This aspect was used to compare different variations, including or excluding certain cost types such as the initial investment for the tube as well as maintenance costs for public roads used by the trucks.
Each of the three scenarios consist of two major parts, the investment phase and the operation profile. In each of these elements the determining components and their attributes are defined (costs as well as environmental parameters). In order to run selected calculations (in- or excluding the investment phase, comparing two or all three scenarios) elements might be disabled before the actual calculation is started. The current approach assumes a duration of 6 months for the investment phase followed by 25 years of operation. These values can be adapted but for comparability of results the phase lengths should be synchronised between scenarios.

3.3 Preliminary Results

First comparisons have been run base on a preliminary data set which is subject to refinements in the coming months. This first analysis already shows that the hyperloop saves cost and has less environmental impact in operation compared to the trucks that are performing these transports today. The NPV will become better after appox. 10 years while the GWP will reach the break-even after two years. Depending on the energy mix, the electric truck will be a serious competition to the CargoLoop, especially because this approach is realizable in the coming months and can be realized by successively exchanging the existing trucks. It will therefore perform better in both economic as well as environmental terms in the operational phase. This means that the comparison of the different scenarios is heavily influenced by the concept of considering the investment costs. The infrastructure for the trucks is already existent and has to a large extent realized by public investments which makes it difficult to justify the CargoLoop under solely private economic aspects.

The current status of the model is that a general structure for each of the three scenarios has been defined and some initial input data is available (especially for the hyperloop case). However, for the final analysis the model needs refined especially for the two truck-based cases. Furthermore, realistic, and detailed input data is needed to carry out the actual analysis.
Therefore, the sample charts in figure 1 provide an overview what type of results is to be expected once the final analysis will take place.

4 Conclusion and Outlook

4.1 Status of the Project

The current status half a year before the project ends is that the LCPA model structure has been prepared and assessments with preliminary data sets have been performed. Whenever new and more detailed data can be obtained, the analysis is updated. This is especially required when the prototype definition evolves leading to changed circumstances with respect to the amount of cargo, the realisation of the demonstrator or the current economic situation which might require fundamental changes to the planned prototype site. Therefore, final results will not become available before the end of the project in May 2024.

4.2 Next steps within and beyond ePIcenter

Despite the aforementioned refinements, the LCPA model will be adjusted if necessary before the final analysis will be carried out close to the end of the ePIcenter project. These calculations will lead to a conclusion whether the CargoLoop will provide economic or environmental advantages over the solutions using diesel or electric trucks.

In parallel, discussions are already ongoing with car manufacturers to identify the final location for a real-life demonstrator. Depending on the decision and the success in convincing investors or funding authorities, the realization of the demonstrator might be realistic within three to five years after the end of the ePIcenter project. Once this happens, the system will again undergo and LCPA analysis to evaluate the current system compared to the predecessor solution but to also get additional information about the precision of the LCPA models which will result in further improvements of the application.

References

1. JOULES consortium: Deliverable 21-1 Conclusion and Summary of WP findings and Political Recommendations (2017).
2. HS EL paper