

Final report

1. Project details

Project title	eWorkVehiclePower
File no.	64020-1051
Name of the funding scheme	Energiteknologisk Udviklings- og Demonstrationsprogram
Project managing company / institution	Banke ApS
CVR number (central business register)	32773974
Project partners	Converdan A/S, University of Southern Denmark
Submission date	30 September 2023

2. Summary

English Version

The eWorkVehiclePower project comprised two distinct workstreams. The first workstream, had the aim of developing a hybrid fuel-cell battery powering unit for working vehicle applications (refuse vehicles, mobile cranes, street sweepers ..etc). The second workstream developed an ultra-high efficiency DC-DC power conversion concept capable of converting and controlling current within and from the power unit compartments of the powering unit.

Banke ApS had primary responsibility developing the powering unit, and Converdan A/S and SDU were focussed on the DC-DC power conversion.

Given the distinct nature of the workstreams, the final report for the project will include separate sections for the two workstreams in each section titled "Hybrid fuel-cell power unit" and "Power conversion" respectively.

Hybrid fuel-cell power unit

Banke ApS' goal was to develop an operational prototype of an integrated battery/fuel-cell powering unit on a Euro V Mercedes Econic chassis converted from an internal combustion engine burning compressed natural gas (CNG) to full-electric operation using a hybrid lithium-ion battery pack and hydrogen fuel-cell system.

The technical development of the system, including the control software system was completed successfully.

However, while the technical development was completed as planned, a key finding of the project was that hydrogen is not a commercially viable energy carrier for automotive applications. This conclusion is based on the significant energy losses which are unavoidable in fuel-cell systems, together with a critical lack of maturity in the supply chain for fuel-cell system components.

Power conversion

Converdan's goal with the project was to develop a working prototype of a bidirectional galvanically isolated DC/DC converter with high conversion efficiency. This product will be able to increase energy efficiency in different markets including transport, energy storage and the marine sector.

The Centre for Industrial Electronics (CIE) at SDU has extensive experience in research and demonstration of ultra-high efficiency DC-DC converters for battery charging and similar applications and has worked closely with Converdan on this project to realize the eWorkVehiclePower project objectives.

A working lab-prototype has been built and tested. The main goal of energy efficiency has been met with a conversion efficiency of above 98% for a wide range of operating areas. The initial goal was above 96% between 25-100% load, which corresponds to 6.25 – 25kW. The prototype utilizes state-of-the-art MOSFET transistors with Silicon Carbide technology. This is one of the drivers for the high conversion efficiency as their electrical resistance is lower resulting in less heat dissipation. The SiC MOSFETs are also able to operate at higher frequencies. This enables smaller and more energy dense magnetic components, which are usually the most costly and bulky components of a power converter. A high frequency magnetic component also requires less copper and core material making it cheaper and more environmentally friendly from a manufacturing point of view.

The prototype is a forerunner of an upcoming product that will be incorporated in fast-charging of EVs for personal- and heavy transport, energy storage and marine transport.

På Dansk (Summary in Danish)

eWorkVehiclePower-projektet omfattede to særskilte workstreams. Den første workstream havde til formål at udvikle en hybrid, brændselscelle / batteridreven enhed til køretøjer som fx renovationsbiler, mobilkraner, fejmaskiner mv. Den anden workstream havde til formål at udvikle et ultrahøjeffektivt DC-DC strømkonverteringskoncept, der er i stand til at konvertere og styre strøm i og fra strømforsyningsenheden.

Banke ApS havde det primære ansvar for at udvikle strømforsyningsenheden, og Converdan A/S og SDU havde fokus på DC-DC strømkonverteringen.

I betragtning af at de to workstreams var særskilte, vil denne opsummering på dansk indeholde separate afsnit under overskrifterne "Hybrid brændselscelle" og "Strømkonvertering".

Hybrid brændselscelle

Banke ApS' mål var at udvikle en operationel prototype af en integreret brændselscelle / batteridreven enhed på et Euro V Mercedes Econic chassis ombygget fra en forbrændingsmotor, der brænder komprimeret naturgas (CNG), til fuldelektrisk drift ved hjælp af en hybrid litium-ion batteripakke og et brint brændselscellesystem.

Den tekniske udvikling af systemet, herunder styresoftwaresystemet, blev gennemført med succes.

Mens den tekniske udvikling blev afsluttet som planlagt, var et centralt resultat af projektet, at brint ikke er en kommercielt levedygtig energibærer til bilindustrien. Denne konklusion er baseret på de betydelige energitab, som er uundgåelige i brændselscellesystemer sammen med en kritisk mangel på modenhed i forsyningskæden for brændselscellesystemkomponenter.

Strømkonvertering

Converdans mål med projektet var at udvikle en fungerende prototype af en tovejs galvanisk isoleret DC/DC-konverter med høj konverteringseffektivitet. Dette produkt vil være i stand til at øge energieffektiviteten på forskellige markeder, herunder transport, energilagring og marinesektoren.

Center for Industriel Elektronik (CIE) på SDU har stor erfaring med forskning og demonstration af ultrahøjefektive DC-DC-konvertere til batteriopladning og lignende applikationer og har arbejdet tæt sammen med Converdand i dette projekt for at realisere eWorkVehiclePower-projektets mål.

En fungerende laboratorieprototype er blevet bygget og testet. Hovedmålet om energieffektivitet er blevet opfyldt med en konverteringseffektivitet på over 98 % for en lang række driftsområder. Det oprindelige mål var over 96 % mellem 25-100 % belastning, hvilket svarer til 6,25 – 25kW. Prototypen anvender state-of-the-art MOSFET transistorer med siliciumcarbid (SiC) teknologi. Dette er en af årsagerne til den høje konverteringseffektivitet, da deres elektriske modstand er lavere, hvilket resulterer i mindre varmeafledning. SiC MOSFET'erne er også i stand til at fungere ved højere frekvenser. Dette muliggør mindre og mere energitætte magnetiske komponenter, som normalt er de mest kostbare og omfangsrige komponenter i en strømomformer. En højfrekvent magnetisk komponent kræver også mindre kobber og kernemateriale, hvilket gør den billigere og mere miljøvenlig set fra et produktionssynspunkt.

3. Project objectives

At the outset, the eWorkVehiclePower project had three broad objectives as follows:

1. Develop a modular and scalable hybrid fuel cell battery powering unit based on existing market leading components within fuel cells and batteries for mobile applications. The preliminary assumption was that a 4-5 kW fuel cell system with 3 kg hydrogen fuel capacity would be used.
2. Develop an ultra-high efficiency DC-DC power conversion concept capable of converting and controlling current within and from the different power unit elements.
3. Test and demonstrate mock-up and operational prototypes for high potential market segments.

Hybrid fuel-cell power unit

For Banke ApS the technical objective was to integrate a fuel-cell system (stack and fuel tank) onto the chassis of a 27-ton working vehicle converted from CNG to full-electric operation. A commercial objective was also defined, namely to “assess market up-scaling possibilities and barriers”. This assessment covered the commercial viability of fuel-cell solutions for automotive applications, the competitive landscape for such solutions and also the maturity of the components and the associated supply chains for fuel-cell systems.

Power conversion

The goal for Converdan and SDU was to develop a working prototype of a galvanically isolated DC/DC converter that could interface high-voltage batteries as found in the eWorkVehiclePower and other electrical utility vehicles and cars as well as energy storage solutions. The use-case of the eWorkVehiclePower vehicle did not directly require bidirectional power capability but the market is moving towards V2G (Vehicle-to-Grid) integration, and this feature is deemed a necessity for a competitive solution that can contribute to a better utilization of energy. Along with these features the main goal of the prototype was to achieve a very high conversion efficiency. The obvious reason for this is to waste as little energy as possible but in a bidirectional converter the energy travels through the converter twice so any energy loss is doubled which means efficiency is even more important in this case.

4. Project implementation

Hybrid fuel-cell power unit

From a technology point of view the project evolved as foreseen by the overall project plan and according to the agreed milestones. The interface from Banke ApS to the power conversion workstream being carried out by Converdan A/S and SDU worked smoothly.

The initial sketch-out for the hybrid fuel-cell battery power unit was based on a 4-5 kW fuel-cell system and a 3kg hydrogen tank. At the outset of the project Banke ApS conducted an exhaustive market scan and RFQ process with all of Europe's main suppliers of fuel-cell systems. In November 2020 ten companies were invited to respond to an RFQ. This process was challenging on many levels as suppliers of fuel-cell systems were generally unwilling to commit to lead-times for either fuel-cell stacks or for fuel tanks. Even allowing for supply chain issues that might have resulted from COVID-19 related challenges, already at this point in the process Banke ApS began to suspect that the maturity of the components and the supply chains for fuel-cell systems was less than ideal.

On the plus side however, Banke ApS found a partner in E-Cap Mobility GmbH from Winsen, near Hamburg who were able to provide a fuel-cell stack and hydrogen tank and to work the Banke ApS on the integration of the system with the Banke ApS electric-vehicle chassis.

Banke ApS and E-Cap Mobility (through its sister company Clean Logistics GmbH) also discussed how the commercialisation of the resulting eWorkVehiclePower for the German market might be done.

As a supplier to the project E-Cap Mobility GmbH also advised that the initial assumption of a 4-5kW fuel-cell would not enable an acceptable level of efficiency to be attained. The losses associated with running such a system at maximum capacity would be prohibitively high. It was thus decided to proceed with a fuel-cell system rated at 63kW, with a view to running the system at 30kW at which output level an efficiency of 51.3% could be attained. The overall system that was thus implemented ended up comprising a 198kWh battery system together with a 63kW fuel-cell system and a 6.5kg hydrogen tank.

Whilst this change of specification did not impact the implementability of the fuel-cell solution, it was clear that the need to over specify the fuel-cell stack would have a significant impact on the cost of the system and therefore on the commercial viability.

At the outset of the project three risks were noted:

1. Low acceptance of hydrogen as a storage technology in the future energy systems: The use of hydrogen for electric mobility will not become a widespread market standard, e.g., due to energy losses in energy conversion and for security reasons.
2. Battery/fuel cell technology: Low efficiency and poor reliability in coupling of the battery and fuel cell storage systems to deliver the required power.
3. Large-scale fuelling: Fuelling requires cost-competitive equipment that can fulfil security requirements.

Each of these risks were rated as “low” in probability but “high” in impact. Due to the underlying nature of the fuel-cell systems and supply-chain, all three of these risks came to be experienced by the project. Whilst this did not impact on the project’s ability to implement the solution, each risk significantly impacts the commercial viability of the implemented solution, and taken together they deal a fatal blow to the viability of hydrogen as an energy carrier for automotive applications.

- Hydrogen had been unequivocally rejected by the passenger-vehicle market, largely due to the fact that fuel-cell vehicles can, at best, only reach around 33% in “turbine to tarmac” energy efficiency. Full-electric vehicles can justifiably claim up to 80% efficiency.
- Given the very low volume of vehicles that could be in scope, components such as fuel-cell stacks and hydrogen tanks have little to no chance of ever being produced at scale and will thus impose a prohibitive system-cost penalty which can be added to the extra costs associated with higher energy requirements.
- With no realistic prospect of hydrogen vehicles becoming widely accepted in the market, the business case for widespread, large-scale fuelling also collapses. Just one week before writing this report in late-September 2023, Denmark’s biggest operator of hydrogen filling stations, Everfuel, announced that it was closing all of its hydrogen filling stations in the country.

Overall then, regarding unforeseen problems and obstacles experienced during the project, it became clear that, despite having existed for more than half a century, the offerings available for fuel-cell stacks and hydrogen tanks were far from mature. One of the project’s key takeaways is that it is likely that this market will never reach maturity and scale production. Similarly, the assumption that smaller fuel-cells could be a pragmatic solution to attain the output and efficiency levels needed was not observed in practice.

Power conversion

Initially the goal for the project was to develop a converter that could interface low voltage (12-120VDC) batteries and fuel cells. This prototype was to be developed in conjunction with SDU and the PhD-student’s project. However, as the project evolved, and the commercial viability of a fuel-cell hybrid working vehicle became less obvious, the objectives for the power conversion workstream were updated. Instead, a high voltage battery interface was investigated as this proved to have a bigger impact and with wider market potential in addition to electric vehicle (including the actual specification of the eWorkVehiclePower power unit) and energy storage applications.

The PhD-student from SDU ended his employment at SDU in May of 2022 and was subsequently employed at Converdan A/S. His academic PhD continued after 6 months of sabbatical and as of September 2023 is being completed on a halftime basis. This means that the PhD-thesis is now due for completion at the end of 2025.

The work done in the beginning of the PhD-study by researching topologies suited for wide voltage battery applications, including a full design of a high-efficiency, wide-range low-voltage dc-dc converter, was directly incorporated in the high voltage prototype developed by Converdan. This change of scope during the project

however meant that the prototype has not been compliance tested yet which was stated as one of the original milestones. It is however in a state where a fully compliant product with the same high efficiency is the next natural step in the development.

Following the change to focus on high voltage EV battery charging applications, it was decided that SDU should make a corresponding change of focus of its research and demonstration activities. SDU then decided to design, build and test a 20kW demonstration model of a newly invented converter topology for ultra-high-efficiency DC-DC converters for HV battery charge/discharge applications in EV and energy storage applications (European patent application number 20181543.8 Soft-switching pulse-width modulated DC-DC power converter). The initial results are very promising, achieving a maximum conversion efficiency of 99,0 percent. SDU's results in this area will be considered by Converdan A/S for future DC-DC converter technology improvements.

5. Project results

Hybrid fuel-cell power unit

The original objectives of the fuel-cell power unit part of the project were achieved in full. As described above the initial assumption that a small (<10kW) fuel-cell could be used was quickly seen not to hold and a larger system deployed.

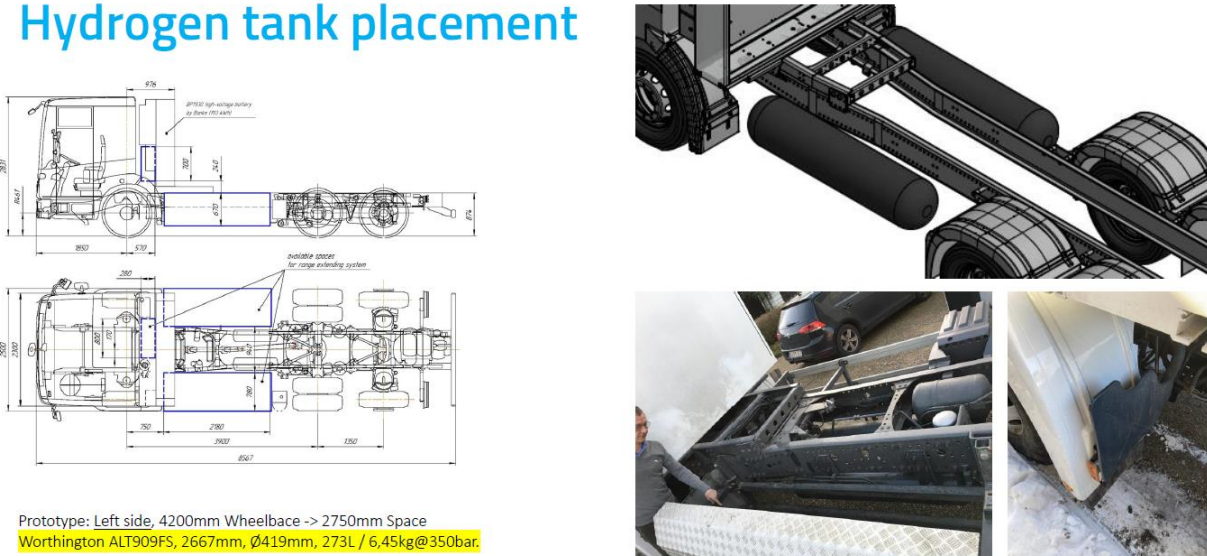
From a technological point of view, the expected results were delivered in that the battery system and fuel-cell system were successfully integrated.

The following photographs show the evolution of the vehicle conversion:



Figure 1: Proposed location of 63kW fuel-cell stack

Hydrogen tank placement



Prototype: Left side, 4200mm Wheelbase -> 2750mm Space
 Worthington ALT909FS, 2667mm, Ø419mm, 273L / 6,45kg@350bar.

Concept: One or both sides, 3900 – 4500mm wheelbase

© 2020 E-Cap Mobility GmbH. All rights reserved, also reference the disposition, utilization, reproduction, editing, passing on and also application for property rights.




Figure 2: Proposed location of 6.45kg hydrogen tank



Figure 3: Side view of converted truck with fuel-cell stack between axles



Figure 4: Side view of converted truck with hydrogen tank between axles



Figure 5: Close up of hydrogen tank and fuelling nozzle

The technological outcomes of the fuel-cell hybrid power-unit were strongly positive, and the system was completed as planned. However, the commercial outcomes were less encouraging.

The idea for the project was based on the belief that an alternative energy carrier (to pure battery operation) would be viable in the market.

We can now see that hydrogen is not an economically viable energy carrier for automotive applications (including both passenger vehicles and working vehicles like the one demonstrated in the project).

Overall system inefficiencies mean that a fuel-cell vehicle will typically use three times as much electricity per driven kilometre as a pure-battery vehicle with a comparable specification in terms of gross vehicle weight and payload.

Operating costs for a fuel-cell vehicle will always be higher than for a battery-electric equivalent.

The lack of maturity and scale in the supply chain for fuel-cell system components in turn means that a fuel-cell working vehicle will be priced significantly higher than a battery-electric equivalent.

At the start of the eWorkVehiclePower project in 2020 the typical market prices for a heavy duty working vehicle with a fuel-cell power unit was of the order of [€800.000/DKK6million](#). The estimated market price for the eWorkVehiclePower vehicle is of the order of DKK5million.

For comparison, the market price for a 27-ton full-electric Mercedes eEconic is in the range DKK2.5-3million.

The additional two million kroners of cost are attributable to the fuel-cell stack and the hydrogen tank used, each of which cost approximately one million kroners as of 2023.

A further barrier preventing large scale adoption of fuel-cell heavy vehicles is the simple fact that full-electric vehicles now available in the market (both from the major truck manufacturers such as Mercedes, Scania, DAF, but also from truck converters like Banke ApS) meet the needs of 90% of all journeys driven by heavy-duty vehicles.

Put another way, of the 400.000 trucks sold in Europe every year, only 40,000 would ever be in scope for using hydrogen as an energy carrier. With volumes this low, it will be impossible for a mature, competitive market for fuel-cell system components to be established.

This in turn implies that the market for the fuel-cell power unit developed during the project will be much more limited than anticipated when the project was started (note that this observation applies only to the fuel-cell power unit, the commercial potential in the power electronics solutions developed is much more promising.) Banke ApS is not including sales of fuel-cells variants of its powertrain in future business plans. Should a customer (or customers) require a fuel-cell vehicle with a specification similar to the eWorkVehiclePower solution Banke ApS will be able to consider providing it however.

The business case for a widespread distribution network for hydrogen as an energy carrier is similarly fanciful, and Banke ApS does not expect to see large-scale investment in hydrogen infrastructure at any point in the next 15 years.

This is not to say that green hydrogen has no role to play as the world transitions to a net-zero economy. On the contrary in fact.

At present the world consumes approximately 100 million tonnes of hydrogen, which is mainly used in oil refining, fertiliser production and heavy industries such as the manufacturing of steel. 98% of the hydrogen

used today comes from methane or coal, and the production of this hydrogen is responsible for 2% of all CO₂ emissions, equivalent to the emissions from the global aviation industry.

Hydrogen is an industry to be de-carbonised, not an immediate solution to the problem of the de-carbonising other industries such as transport.

This is one of the key findings from the project, and a topic that was discussed at length during a seminar Banke ApS hosted in June 2022. Banke ApS exhibited various solutions included the eWorkVehiclePower vehicle, and our partner E-Cap Mobility GmbH exhibited their own fuel-cell tractor unit.

Banke ApS welcomed approximately 100 guests to Nordborg and the eWorkVehiclePower project and solution was one of the topics discussed during the day.

The broadly accepted outcome of a panel debate on the topic of “Hydrogen as a fuel” was that it would be better to focus investments on transitioning the 90% of heavy vehicles that can do so over to full-electric operation (for example by installing charging infrastructure and continuing to build out the renewable network). This makes more sense on all fronts that than investing in hydrogen as a fuel or worse still, hydrogen as a “component” in even less viable e-fuels. There will be a big market for green hydrogen, but for the foreseeable future this will be used for replacing “black” hydrogen produced from fossil fuels.





Figures 5 & 6: eWorkVehiclePower on display at Banke ApS Open Day, June 2022

The conclusion regarding the fuel-cell power unit is that while it was possible to develop and build the solution, the commercial viability of the resulting product is, at best, very limited, and in reality, non-existent.

Power conversion

As mentioned above the original voltage and power requirements were changed during the project. The final prototype did meet its goal of high conversion efficiency across a wide range of battery voltage. See: 5.2

To cover a wide range of high-voltage batteries the converter is designed to interface batteries with a voltage range of **400 – 850 VDC**. This covers the battery voltage of the eWorkVehiclePower which requires **540 – 680 VDC**. There is a trend of going towards higher voltages in battery packs both in energy storage and electric vehicles as this leads to a more efficient solution requiring less cable cross-sectional area to move the same energy thus using less copper. Because of this the converter is designed to for higher voltages than just the battery pack of the eWorkVehiclePower.

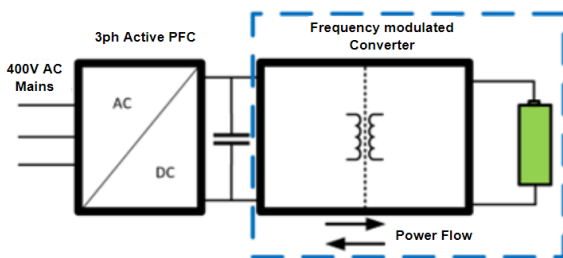


Figure 7: Traditional approach using single-stage converter

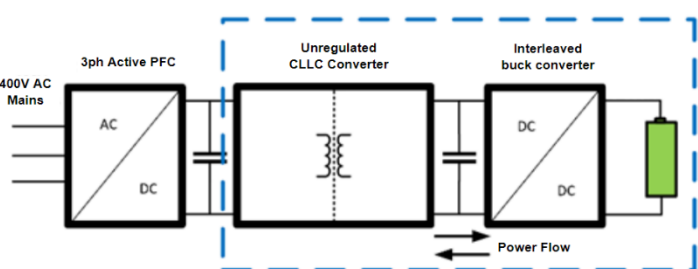


Figure 8: Two-stage solution used in eWVP converter

The system is split into two separate converters. Normally a DC/DC converter is designed as one unit. When a wide voltage range is required, great complexity is involved in optimizing the converter as it needs to operate at different extremes which basically are each other's opposites. This means that many compromises must be made to end up with a final design and the most important component – the transformer is often quite intricate which can complicate manufacturability. When splitting the converter into two, the transformer of the isolated converter operates at a single frequency and with a turns-ratio of 1:1 which makes it a lot simpler and easier to optimize. To implement voltage regulation an interleaved buck converter is implemented and put in series with the isolated converter. This type of converter, with the help of modern Silicon Carbide (SiC) MOSFETs can operate at very high efficiencies while maintaining relatively low complexity.

For these reasons the converter prototype has high conversion efficiency across a wide voltage range with few compromises in terms of optimal magnetic component design.

5.1 Hardware prototype

The two separate converters are built and tested separately.

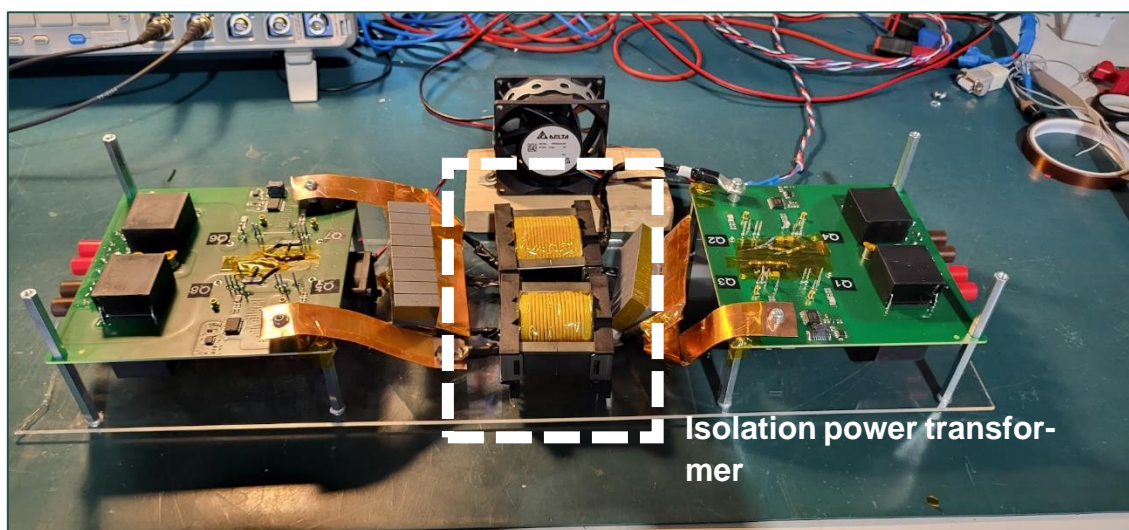
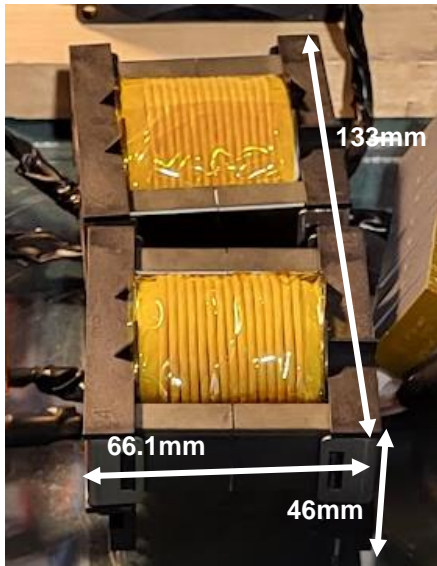


Figure 9: Unregulated isolated converter lab-bench test prototype



By keeping the isolated converter's operating range very narrow a highly optimized transformer can be designed. The dimensions of the transformers (two are coupled in series to obtain a 25kW power rating) take up a volume of:

$$46 \cdot 133 \cdot 66.1 \text{ [mm]} = 0.4 \text{ [L]}$$

This results in a power density of $\frac{25 \text{ kW}}{0.4 \text{ L}} \approx 61.8 \frac{\text{kW}}{\text{L}}$

A comparable off-the-shelf solution from Premo designed for 23.2kW achieves a power density of $26 \frac{\text{kW}}{\text{L}}$, less than half of the eWVP prototype.

Figure 10: Isolation transformers

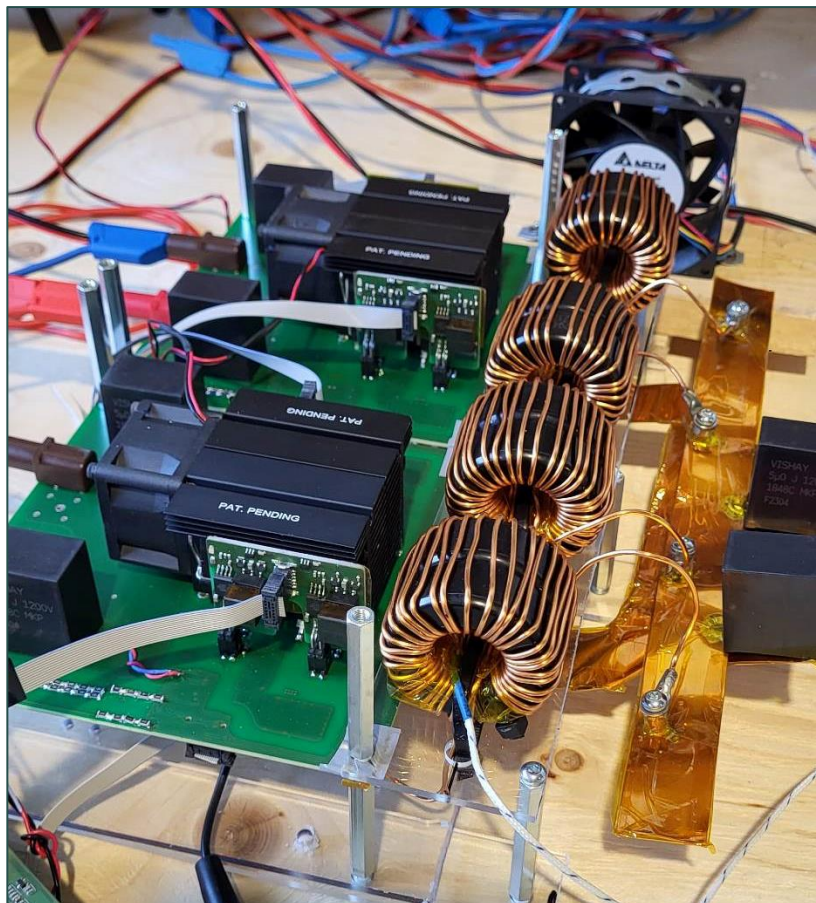
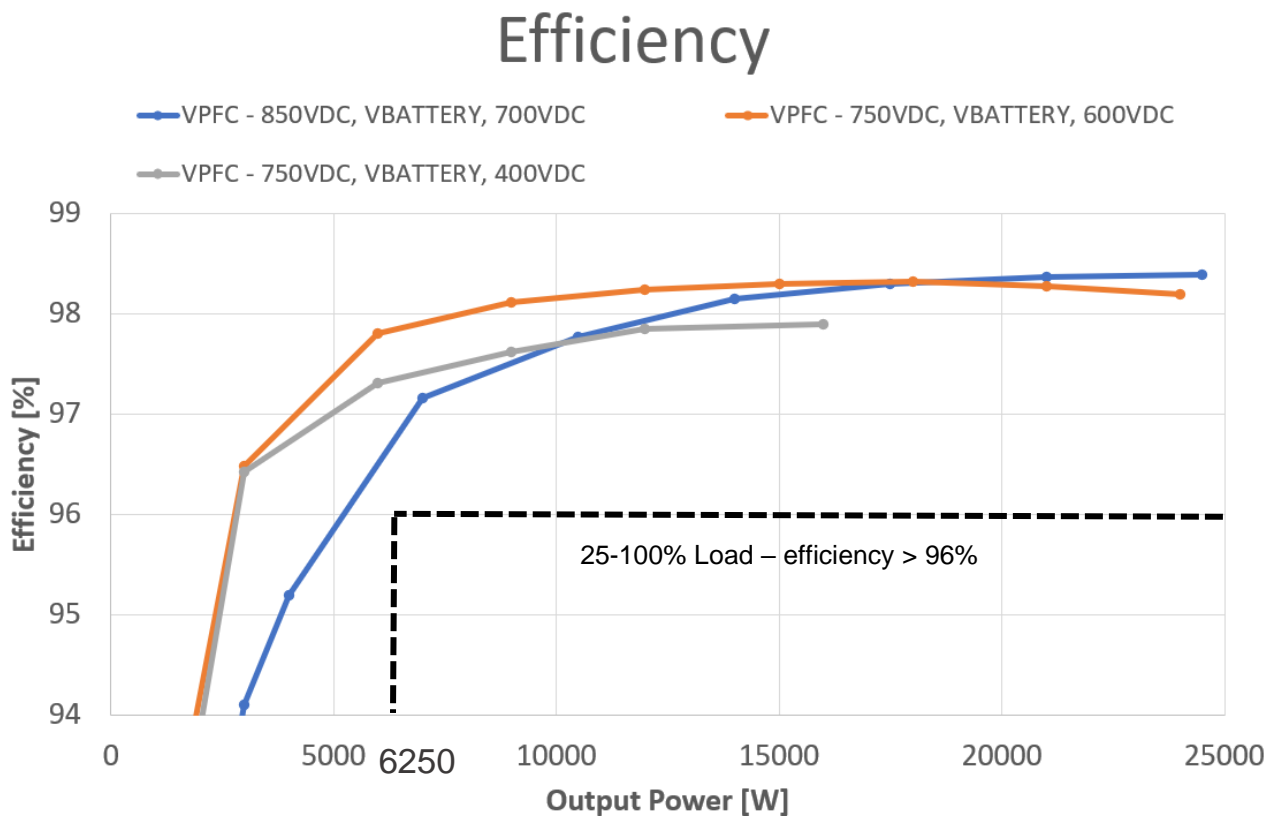


Figure 11: Interleaved Buck converter lab-bench prototype

5.2 Efficiency

High conversion efficiency of the converter is the main goal of this prototype. The target is an efficiency above 96% from 25 – 100% load. As can be seen from the figure below the target is met through the whole load range from the low voltage of 400V to the maximum voltage. A margin of about 2% is present, which is a good result and on par with the newest research-based converters. 25% load is 6.25kW

The 400 VDC efficiency curve stops at 16 kW as the output current is limited -> $400\text{ V} \cdot 40\text{ A} = 16\text{ kW}$



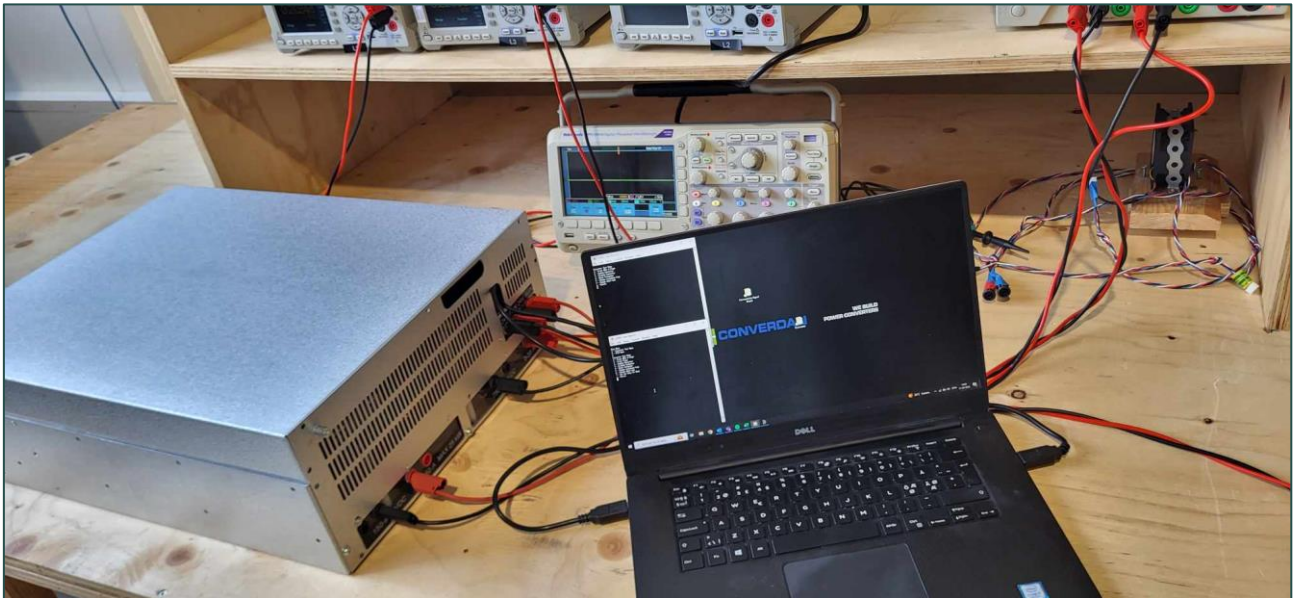


Figure 12: Finished lab prototype in 19" 4RU cabinet controlled from a lab PC

6. Utilisation of project results

Hybrid fuel-cell power unit

The technical solution developed will become part of Banke ApS' product portfolio. However, sales of the solution developed are not included in future business plans for Banke ApS as the commercial viability of the solution is limited.

The competitive situation that should be considered is the market for electric trucks in broad terms rather than the much narrower potential market for hydrogen powered vehicles. In the market for electric trucks, competitor products are available from all the major European truck manufacturers including Daimler/Mercedes, Volvo, Scania, DAF and MAN.

In addition to these major players, a number of smaller vehicle re-builders (including Banke ApS) are in the market, for example Swiss-based Quantron who offer a portfolio including a fuel-cell tractor unit comparable to that exhibited by E-Cap GmbH in Nordborg in June 2022.

However, the competitive situation is certainly far from being clear. Quantron's solution is based on a chassis from MAN, and as recently as June 2022 MAN's CEO, Alexander Vlaskamp, had this to say about the viability of hydrogen powered trucks: "Hydrogen-fuelled trucks will only play a small role in Europe's zero-emissions transport future, with the vast majority of logistics vehicles set to be battery electric ... E-mobility is coming now. The technology is mature and most efficient. In our estimation, 80% or even 90% of logistics trucks will be electrically driven ... hydrogen or biofuels might be suitable for vehicles carrying extremely heavy loads, such as 150-250 tonne wind turbines." (Source: <https://www.hydrogeninsight.com/> June 23rd 2023)

MAN's parent company, Traton, is part of a joint-venture which also includes Daimler and Volvo and which is tasked with carrying all three companies efforts within fuel cell solutions. Volvo states that it will have fuel-cell vehicles available in "the second half of the decade". The vehicles being developed are long-distance tractor units similar to those we have seen from E-Cap and Quantron rather than being aimed at the working vehicle market that the eWorkVehiclePower solution was intended for.

Overall then, while the eWorkVehiclePower solution has been successfully demonstrated from a technical point of view, the project is not expected to have a meaningful commercial impact for Banke ApS.

The fuel-cell power unit solution itself will thus not contribute directly to realising Denmark's energy policy objectives. However, by demonstrating the lack of viability of hydrogen as an energy carrier for working vehicle applications, it is expected that the project will help accelerate the transition to full battery-electric vehicles, which, by avoiding the energy-inefficiency inherent in fuel-cell systems will in turn help realise energy policy objectives.

Power electronics

As mentioned previously the technologies that have been refined and tested with this lab prototype will be the steppingstone for a product that can be sold off-the-shelf to companies developing fast-charging or energy storage solutions. The product will be a Converdan A/S product.

The project has spurred increased research and development efforts from Converdan's side after the project is finished which is estimated will employ 1-2 full-time engineers for at least one year during development.

Few competitive off-the-shelf products exist as most converters in this market are developed to a specific use-case and sold as such. A competitor product can be bought in a similar 19" 4RU cabinet with max. 800VDC and 25kW. The product spurred by this project is expected to double the power, 50kW, in the same volume of space with a higher voltage range and rating.

In addition, the project is expected to form the basis of a PhD thesis expected to be completed during 2025.

7. Project conclusion and perspective

Hybrid fuel-cell power unit

The hybrid fuel cell battery powering unit demonstrated innovatively combines minimal usage of relatively costly fuel-cell systems and maximum usage of technically mature and cost-competitive battery systems. It provides the necessary duty cycle power in areas where the electrical grid infrastructure cannot support large-scale battery charging, and it avoids the need for power generation from on-board combustion engine driven sources.

In this regard the project has been a success. Banke ApS also stands to benefit from the outputs of the project delivered by Converdán A/S and SDU in its non-fuel-cell powertrain solutions.

The commercial viability of fuel-cell systems, and the general viability of hydrogen as an energy carrier for automotive applications, were not successfully demonstrated. Inefficiencies in the fuel-cell system result in significant energy losses and an overall turbine-to-tarmac system efficiency of around 35%. This compares very unfavourably to the typical 80% efficiency attained by comparable full battery-electric power units. Operating costs for fuel-cell power units are significantly higher than those of full battery-electric solutions.

The acquisition costs (i.e. purchase price) for a heavy duty working vehicle with a fuel-cell power unit were similarly found to be prohibitively high due to a critical lack of maturity in the supply chain for fuel-cell system components. Reflecting the challenges faced by fuel-cell component manufacturers, Banke ApS' fuel-cell partner during the project, E-Cap Mobility GmbH went bankrupt in May 2023.

The abandonment of fuel-cell powertrains by manufacturers of passenger cars, and the introduction of full-electric commercial heavy vehicles covering approximately 90% of vehicle duty-cycles will leave only a very narrow segment of the automotive market in scope for fuel-cell solutions. This will in turn prevent manufacturers of key systems reaching scale production, thus ensuring that acquisition costs remain high, while at the same time, costs continue to fall for full battery-electric solutions.

Power electronics

A prototype has been developed and tested which achieved the main goals of wide voltage range on the battery-side of the converter while maintaining a high and relatively "flat" efficiency curve. The biggest focus has been on developing and optimizing the magnetic components of the converter while also running the state-of-the-art Silicon Carbide (SiC) MOSFETs at high frequencies and keeping the power losses low. The results have inspired confidence in developing a new-generation of DC/DC converters for energy storage and EV fast-charging with the topology and components that has been researched during this project.

The next step is to have a demonstrator product available to customers interested in developing their own charging or storage solutions.

While feeding into a product that is a direct spinoff from the eWVP prototype the technology that has been uncovered with high-frequency magnetics and 2-stage converters may also be used in other future products with similar use-cases but different voltage or power levels.

8. Appendices

- Data sheet for Banke eWorkVehiclePower solution.



Conversion system for work vehicles

Full electric or Fuel-cell hybrid

Prototype based on converted MB Econic

Euro 5/Euro 6



FIG.1. Vehicle with garbage compactor. One side of the vehicle is available for optional storage boxes (red boxes)

Flexible modular work-vehicle conversions

With the modular design of the CL-Banke conversion strategy for work vehicles, we are able to offer you a flexible solution for the conversion of your diesel-powered work vehicles. Depending on the application needs, we can provide both fully electrically or fuel-cell hybrid powered conversions. We can convert both crane, hook-lift, refuse collection, sweeper as well as sewage and drainage vehicles.

Full electric or fuel-cell hybrid? Your needs – your choice.

The full electric conversion offers a quick shift to convert to an environmentally friendly work vehicle, especially with an all-year-round, known daily power demand. For the full electric version, the battery pack can vary from a basic 128 kWh to 384 kWh, providing you with the range needed for your purposes. The battery can be charged with the on-board 22 kW charger or using CCS fast charging.

For high power demanding applications, or when the vehicle is working in a 2-work shift setup, the truck can be fitted with fuel-cell technology to increase the working range and working-time. For the application with a varying daily power demand, the fuel-cell hybrid will offer flexibility and a fast-refueling solution that will work all year round. This fuel-cell hybrid is also the best choice when the vehicle load capacity is critical or when the vehicle is used in a variety of route setups, but also as salt sprayers in the winter time. Hydrogen refueling will take between 5 and 15 minutes, depending of the number of tanks installed.

When fitted with fuel-cell and hydrogen tanks, the basic battery will contain 128 kWh and the hydrogen tank system will consist of 1-3 tanks containing each 90 kWh of usable energy with a total of 398 kWh.

Want to know more?

For more information on how to convert your work-vehicles into an environmentally friendly version on the way to carbon neutrality, contact the Clean Logistics sales team.

Banke ApS DK-6400 Ormstoft 5, Denmark



WEIGHTS AND PERFORMANCE	
Gross vehicle weight	19000 or 27000 kg
Wheel arrangement	6x2-4, or 4x2
Wheelbase	3450mm, 3900mm, 4200mm, 4500mm
System weight addition	1223 kg – 2223 kg depending on kWh of battery and number of Hydrogen tanks
Front-axle weight addition	Minimum 1033 kg (198kWh battery pack behind cabin)
Maximum speed	80 km/h (set by software)
Maximum gradeability	34% @GVW
IP-grade	IP54 (Charging connector IP55, Charging during rain is allowed)
Operating conditions	-20°C to +45°C (above +35°C power derating possible)

TRACTION CAPACITY AND CHARGING	
Full electric battery capacity	128 kWh up to 384 kWh, shared between driveline and E-PTO
Fuel cell Hybrid	218 kWh up to 398 kWh (incl. 128 kWh buffer battery), shared between driveline and E-PTO
Position of batteries	Behind the cabin, and/or between the axles. (Depending on application and buddy)
Position of H2 Tanks	Behind the cabin, and/or between the axles. (Depending on application and buddy)
System voltage	614 V DC (560...710 V DC)
Fuel Cell power capacity	63kW (system efficiency 51.3% @ 30kW)
Battery lifetime	More than 2500 charging cycles between 20 – 100% SOC.
Battery cell protection	Balancing by BMS on all cells.
Battery pack protection	Fully protected against overcurrent, over- and under-voltage, excessive temperature, and overcharging.
Charging time AC	Basic capacity, 11 hours (22 kW AC charging)
Charging time DC	Basic capacity 2 – 8 hours (Max 95 KW), (charging at 0,5 C)
Hydrogen refueling	5 to 15 minutes depending on number of tanks (system pressure 350 bar)

DRIVE SYSTEM	
Total power of traction motor	190 kW nominal, 250 kW temporary.
Transmission	Automatic transmission with PTO for work-application
Power electronics for drive	Constant magnet propulsion motor, Inverter on IGBT transistors
Cooling system	Liquid cooling of electric drive motor and power electronics. Automatic transmission cooling system integrated with water heating system of the cabin.
Electric safety system	<ul style="list-style-type: none"> • Insulation control system • Marking of high-voltage devices • Button "safety stop of high voltage circuit"

AUXILIARY SYSTEM COMPONENTS	
Nominal voltage	24 Volt
Power of DC/DC converter	6 kW
LV Charging	450-900/24 V DC/DC converter
Air conditioning	Optional
Air compressor	Electric, 450 l/min, Pmax 12,5 bar
Cabin heating (full electric)	4 kW water flow heater plus recuperation of energy from driveline cooling system
Cabin heating (fuel cell hybrid)	4 kW water flow heater plus 30kW excess heat from driveline cooling system

Banke ApS DK-6400 Ormstoft 5, Denmark

- Specifications for Converdan DC-DC converter
 - Topology: 2-stage: CLLC with interleaved synchronous buck
 - Bidirectional power capability: YES (full power in both directions)
 - Target efficiency: Min. 96 % (25-100 % load)
 - Design focus to optimize: High efficiency across wide input/output voltage range.
 - DC-voltage: 750 – 950 VDC
 - Battery voltage: 400 – 850 VDC
 - Current: 40A → derate output power from 600V battery voltage
 - Maximum power: 25 kW