

*EVS30 Symposium
Stuttgart, Germany, October 9 - 11, 2017*

The EnergyTube System – A Module based, Scalable Energy System, with Battery and Fuel Cell for Portable, Mobility and Stationary Applications

Jörg Dieter Weigl¹, Felix Friederich¹, Manfred Löprich², Johannes Dörndorfer¹,

¹Unicorn Engineering GmbH, Universitätspark 1/1, 73525 Schwäbisch Gmünd, Germany, joerg.weigl@energytube.de

²Unicorn Energy GmbH & Hochschule für Gestaltung Schwäbisch Gmünd

Summary

Standalone battery systems are mostly developed separately for each application, because they are not standardized. The EnergyTube System is a concept for a standardized and universal energy storage system with battery and hydrogen fuel cell modules. Its modularity allows the usage from mobile applications, to light electric vehicles, and stationary energy storage devices. It is scalable and swappable without impairing the application. A hydrogen fuel cell module with a scalable hydrogen storage module and a hydrogen refueling module has been developed extending the potential for the EnergyTube System. Battery and fuel cell modules can be freely combined to hybrid systems.

Keywords: battery, energy storage, fuel cell, hydrogen, standardization

1 Background History of EnergyTube system

The EnergyTube battery module concept is based on an idea of Johannes Dörndorfer in 2010. Dörndorfer has been working since more than two decades on small electric vehicle drives; by developing application products he found a lot of difficulties with battery packs. Battery pack dimensions, chemistries and the manufacturers were continually changing. Therefore, the idea of a standardised battery pack was developed which is independent on cell chemistry and voltage by an integrated DC/DC voltage converter. This EnergyTube battery module, can safely supply power devices between 9-60 Volt and can be stacked in parallel. It can be swapped or recharged. This concept was awarded at the Green tech awards 2015 [1], and brought to mass manufacturing level with automotive standard in 2017. The concept was provided to IEC for standardization of a battery swap system as the Technical Specification IEC TS 61851-3-3 (under preparation) [2].

At the end of 2016, this EnergyTube battery module concept was further complemented with a fuel cell system fitting in the same standardised tubular format offering a second energy storage form in hydrogen. The complemented modules are: a hydrogen fuel cell module with a scalable hydrogen storage module and a hydrogen refueling module. This supplement energy storage in hydrogen gives the advantage of a tailor-made hybrid system according to the application. Due to their modularity, the hybridization can be changed on momentary demand. The battery module provides safe peak power combined with easy recharging. The

fuel cell modules with the hydrogen storage modules provide advantages in gravimetric and volumetric energy density. The interconnectable hydrogen storage modules can be refueled with the hydrogen fueller module based on a high-pressure electrolysis. Alternative refueling options are hydrogen filling stations [4] or a home refueler from reformer or bottled hydrogen. Also, the development of hydrogen storage module based on chemical hydrides is possible [3]. The idea is to create a complete, flexible and user-friendly fuel cell system application.

2 The EnergyTube Concept

The system contains the EnergyTube module with batteries, the H₂-EnergyTube module with fuel cell, the H₂-StorageTube with the hydrogen for the fuel cell, as well as a H₂-FuellingTube module generating hydrogen with electricity from water, as in Figs. 1, 2, 3, 4. Together, these modules build a scalable energy system with fuel cell battery hybridisation.

2.1 Applications for the EnergyTube System

The modularity allows to cover a very wide range of applications starting from mobile applications like USB-power banks to power tools or portable medical devices, to the extent of light electric vehicles, and stationary energy storage devices, e.g. for renewable energy.

As the energy system is modular and standardized, it can be used for different applications during the day. For example, the EnergyTubes of an e-bike parked at home can be used for the house energy storage. At the same time, you can take out single modules of the home storage for using a power tool or a medical device without influencing the function of the rest of the system.

3 Technologies of the EnergyTube Modules

3.1 The EnergyTube

The EnergyTube Fig.1 is the basic module of the energy system equipped with batteries, battery management system (BMS), near field communication (NFC), and a DC/DC converter, which allows a voltage for the application between 9 V and 60 V independent of the cell voltage. The peak power of one EnergyTube is 300 W at a capacity of max. 100 Wh. The weight is 624 g. Fig. 1 shows the components of an EnergyTube. The EnergyTube has an electrical connection interface on bottom and top allowing to stack up and connect EnergyTubes in parallel with a peak current of the EnergyTube column up to 50 A. The EnergyTube Adapter allowing the connection of any application to the EnergyTubes is a part of the application and contains the communication interface (NFC to e.g., CAN), electronic switches, sensors, and power connections.

3.2 The Hydrogen EnergyTube

The H₂-EnergyTube is a fuel cell based power delivering module as shown in Fig. 2. It has the same NFC communication and electric connecting interface on the bottom [5] of the tube like the EnergyTube with batteries. The upper connection is different with a hydrogen inlet valve for high pressure hydrogen (up to 700 bar operating pressure) and contactless control power and communication interface. The polymer electrolyte fuel cell (PEM-FC) has electric power of 100 W and is air cooled. Water produced from the fuel cell operation and purge is taken out with the cooling air stream.

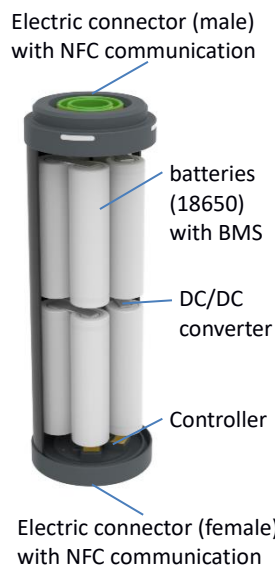


Figure 1: EnergyTube

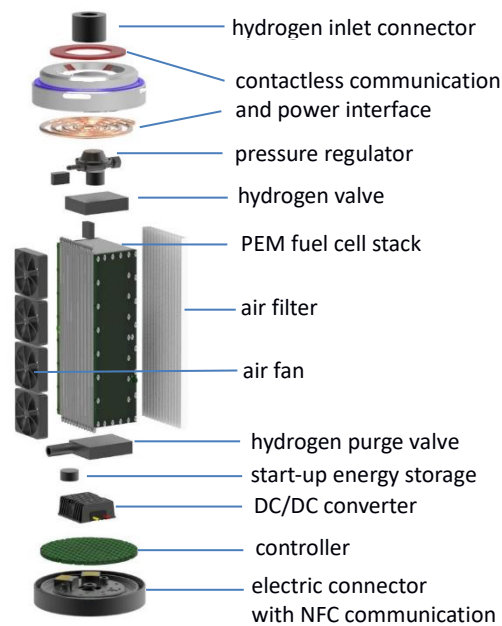


Figure 2: Hydrogen EnergyTube

3.3 The Hydrogen Storage Tube

The H2-Storage Tube (Fig. 3) is a hydrogen storage module providing hydrogen for the H2-EnergyTube. This module can contain in principle any hydrogen source like metal hydride storage, chemical hydride (like PowerPaste [3]) or pressurised storage. The selected hydrogen storage method is a 700 bar pressurised system allowing the storage of the equivalent of 200 Wh electric energy in a single tube size container (59 mm diameter and length 180 mm) and 500 Wh in a double size tube (length 360 mm).

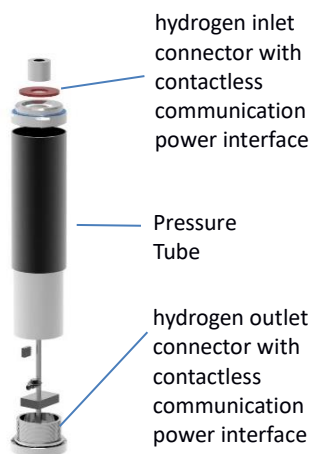


Figure 3: Hydrogen StorageTube

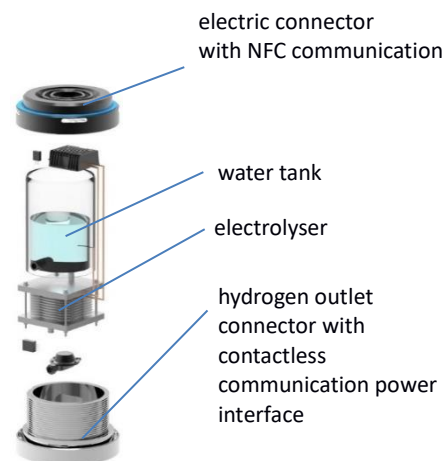


Figure 4: Hydrogen FuellingTube

3.4 The Hydrogen Fuelling Tube




The H2-FuellingTube is a device to generate hydrogen via electrolysis from water with electricity. It is one possible way to refill the Hydrogen StorageTube. Other possibilities for refuelling would be with a hydrogen filling station or a hydrogen home refueller [4], or use chemical hydride to fill the H2-StorageTubes or supply hydrogen directly to the H2 EnergyTube [3].

As illustrated in Fig. 4, the H2-FuellingTubes have an electrical interface on the top and a high-pressure hydrogen interface on the bottom. Deionised water is refilled from the side of the tube. The electrolyser is designed as high-pressure electrolyser providing up to 700 bar compressed hydrogen.

4 The Configurable Fuel Cell, Battery Hybrid System

The modularity of the design allows building and configuration of fuel cell battery hybrid systems according to the application and the very individual user profiles. EnergyTube with batteries are used for peak power demand, H2-EnergyTube with fuel cell contain together with H2-StorageTube about double the energy capacity and have 100 W continues power in comparison with the (Battery) EnergyTube. Table 1 shows capacity comparisons between battery only systems and some fuel cell battery hybrid system configurations.

Table 1: Capacity comparison of battery with fuel cell hybrid systems.

volume of 3 tubes			volume of 12 tubes	
				
300 Wh	400 Wh	500 Wh	1200 Wh	2600 Wh

4.1 Application of the Energy Tube System

A good overview of the application range for the EnergyTube System can be given in Fig. 5. It can be installed into new and existing applications. Its modularity allows the usage from mobile applications, like USB-power banks, to power tools, or portable medical devices, to the point of light electric vehicles, and stationary energy storage devices, e.g. for renewable energy in the kWh to MWh class. Some examples are also shown in Fig.6

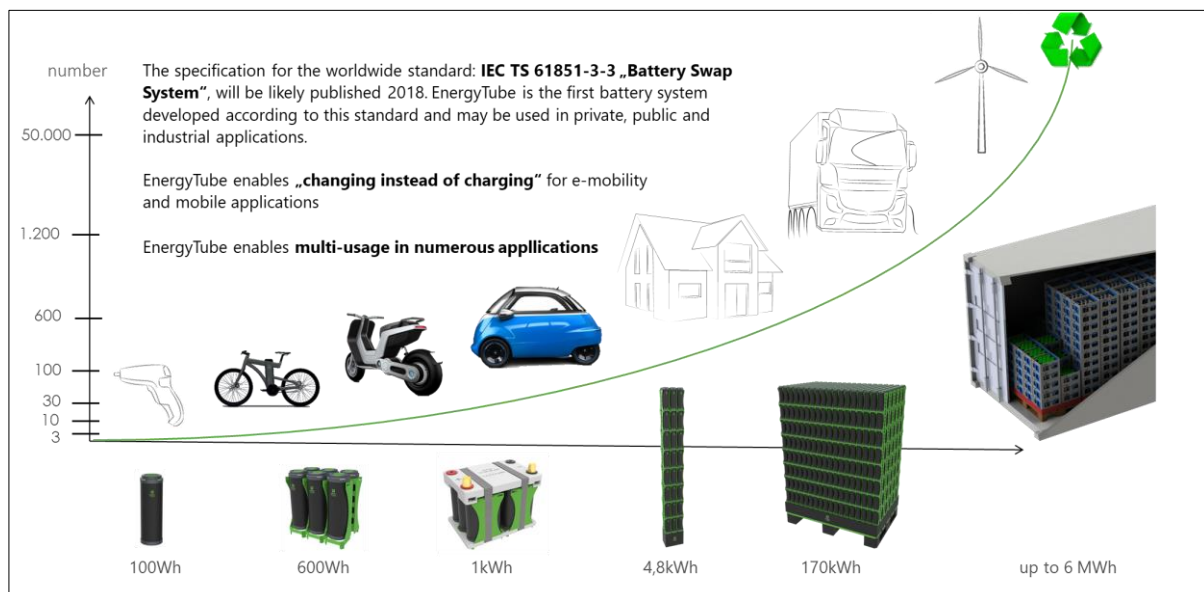


Figure 5: Range of applications for the EnergyTube System



Figure 6: Application examples of EnergyTube system (from right): with USB charger, camp light, solar energy storage, and lawn mower.

4.1.1 Real world data of solar system with EnergyTube battery storage.

Tests were made with a typical house energy storage system, containing of 60 EnergyTubes in a AC grid connected solar system, with 1.2 kW_{peak} solar panels. Fig. 7 shows example screen shots of the real-time data provided through the communication interface. It shows one more fesable application.

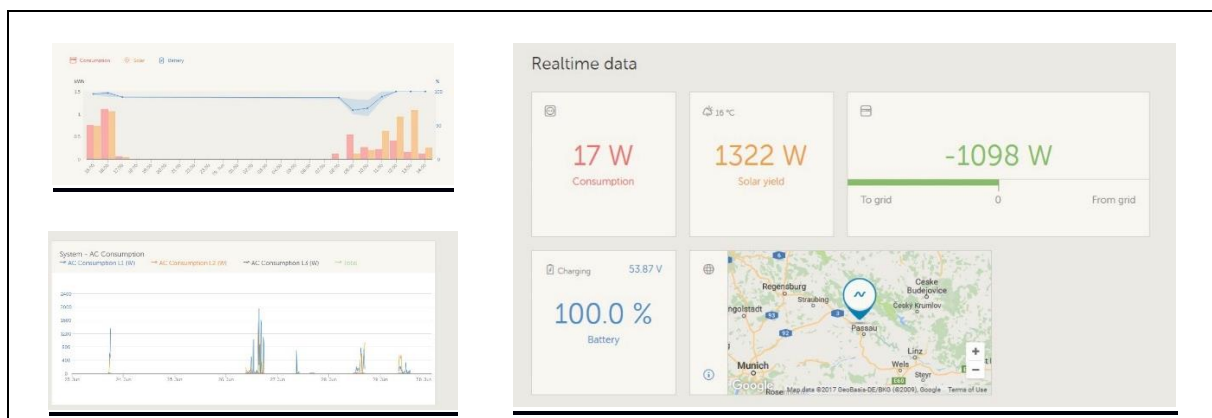


Figure: 7 House energy storage with EnergyTubes (from right) showing the values of battery stade of charge, solar power and power consumption during 24 hours. The AC-consumption on each of the 3phase, and screen shot of the real-time data provided through the communication interface.

4.2 The benefits of the hybrid system

- Flexibility: Scalable from about 0.2 kWh up to 5 kWh per H2-EnergyTube. Hybrid building block system. The dimension will be chosen by the user. Exchangeable between, as well as within stationary and mobile applications. (Key function: plug and play)
- Modularity: Single tubes are replaceable, without disrupting the complete system.
- Performance: Fuel cell technology will be interesting for small scale applications, that means range extension and improved performance of mobile applications.

- Reliability: During fluctuating energy supply, a dynamic operation will be possible
- Cost Efficient: Utilization of same mechanical and electrical parts for all System components.
- Network building: Intelligent system which include: energy management system, remote servicing is possible, power tracking, virtual power plant, increase of efficiency.

4.2.1 They are especially applicable for the following market applications

- Emergency systems which need a fast and reliable electrical supply – (almost no self-discharge of the hydrogen system)
- High capacity and low weight applications (motorised vehicle applications)
- Applications that work independently of the supply network (mains) and which would benefit from long-term storage of solar and wind energy (self-sufficient supply of surveillance cameras, tunnel-lighting in the Alpes, emigrant farms)

4.3 Specifications of the Energy Tube System

A comparable overview of the EnergyTube System Moduels can be found in Table 2.

Table 2: Technical specifications of the EnergyTube system moduels

Description	EnergyTube (battery module)	H2 EnergyTube (fuel cell module)	H2 StorageTube (pressure tank module)	H2 FuelingTube (electrolyze module)
Diameter	59 mm			59 mm*
Hight / Length	180 mm (174 mm connected)		180 mm single tube 360 mm double tube	180 mm*
Weight	624 g	400 g*	300 g*single tube 500 g* double tube	1kg*
Power	250W	100 W	H2 flow 1 Slpm	90 W* (Consumption)
Capacity	100Wh	-	200 Wh* single tube 500 Wh* double tube	1,5 g* H ₂ per hour (up to 800 bar)
System Voltage	9 – 60 V (adjustable by NFC communication)		(12 V* internal)	Input 9-60 V *
Start-up time	Immediately (<4ms*)	< 1 min* Start-up by	Opening time < 10 s*	1 - 2 min*
Start-up voltage	auxiliary power source 12V			-
Communication	Nearfield communication (NFC)[5]		Qi-Standard* or SAE J2799 Infrared*[6,7]	NFC*

*target value

5 Summary and Conclusions

The energy supply system based on EnergyTube Modules and H2-EnergyTube Modules with H2-Storage Tube is a very modular system, allowing to serve a very wide range of applications. The sizing of the tube shape modules is chosen to be easy and safe to handle. It does not have to be declared as dangerous goods as for batteries. Volume manufacturing benefits for fuel cell systems are easier to reach. Easy and fast to swap to have new energy in the application, with long life time by monitoring and memorising the state of health profile of each module. The decoupling with DC/DC converter allows to swap, add or take away modules within the running application and to combine modules with different state of charge or hydrogen filling pressure.

At the current stage, the system has reached prototype status and will have a mass production start in phases beginning with the EnergyTube in 2017 followed by the H2-EnergyTube and H2-StorageTube, and lastly the H2-FuelingTube.

Acknowledgments

Beside the main financing of this development process through Unicorn Engineering GmbH, we would also like to thank our partners in the development process which are: Clean Energy Research Centre at Temasek Polytechnic, Duralite Power Singapore, INEM at Hochschule Esslingen, Staiger GmbH & Co.KG, PTEC GmbH, DLR e.V. Technology Marketing Stuttgart, Brennstoffzellen Cluster Baden Württemberg, and all other partners which will further join.

References

- [1] Green Tec Awards, <http://www.greentec-awards.com>, accessed 2017-01-17, 2015 Nominee Production Category, EnergyTube die Standard Batterie by EnergyTube Holding GmbH
- [2] Technical Specification IEC TS 61851-3-3 (under preparation)
- [3] M. Tegel, L. Röntzsch "Wasserstoff ohne Tankstellennetz-PowerPaste für mobile und autarke Brennstoffzellen", HZwei Magazin für Wasserstoff und Brennstoffzelle, pp.35-37. year 2016, no 4 (Oct),
- [4] Weigl, J., Wang, Z., and Sepahvand, H. M. (2012). Hydrogen Refueling Infrastructure Design for Personal Mobility Devices using Frugal Engineering Approach. Energy Procedia. 29(0), 668-675
- [5] Peng Nengling; Wei Bo; Li Zhenshan; Feng Junqiang, "Research on electromagnetic compatibility performance of new energy bus CAN network," Transportation Electrification Asia-Pacific (ITEC Asia-Pacific), 2014 IEEE Conference and Expo, vol., no., pp.1,3, Aug. 31 2014-Sept. 3 2014
- [7] SAE J2799_201404 Hydrogen Surface Vehicle to Station Communications Hardware and Software, Revised 2014-04-09
- [6] SAE J2601_201612 Standard; Fueling Protocols for Light Duty and Medium Duty Gaseous Hydrogen Surface Vehicles, Revised 2016-12-06

Authors



Joerg Dieter Weigl from Germany (*1977, Ulm), started in his youth with solar vehicles, won in the young research competition. He studied mechanical engineering in Germany and did his Engineering Doctorate on a fuel cell powered motorbike at Universiti Teknologi Malaysia. He worked for National University of Singapore as lecturer in the Future Transportation Track of the Design Centric Program. He completed several full scale electric vehicle project on land, sea and air. He continued at German Aerospace Centre (DLR) at the Institute of Vehicle Concepts and is currently project leader for hydrogen energy systems at Unicorn Engineering in Schwäbisch Gmünd, Germany.



Felix Friederich (*1984) studied physics at Eberhard Karls Universität Tübingen and did his natural science doctorate at Karlsruhe Institute of Technology. He is a member of different standardization groups at CiA, DKE, CENELEC and IEC where he works in the fields of charging infrastructure for light electric vehicles, electrical safety, battery safety, and communication protocols. He has been involved since 2014 in the development and industrialization of the EnergyTube system. He is CEO of Unicorn Engineering GmbH in Schwäbisch Gmünd, Germany.



Manfred Löprich (*1996, Stuttgart). After graduation from high school he made further personal developments, practical experiences and internships in the Design industry. Participation in workshops on Transportation Design at the Pforzheim University, Germany. Studied Product Design at the University of Applied Sciences Schwabach Gmünd, in Germany. Currently employed in the Design department at Unicorn Energy GmbH.



Johannes Dörndorfer (*1966) is the head of advanced development at Unicorn Engineering GmbH. Since 1992, he has been developing drives and battery systems for a variety of applications in the field of electrical mobility. As co-founder of ExtraEnergy e.V. and EnergyBus e.V., he supports the topic of electrical mobility and is a codeveloper of the necessary standards for the communication and energy management of networked systems. Also, the basic ideas for the worldwide battery safety standard BATSO are developed by him, with regard to the future and further development of the market.