skeleton

Automotive applications

for Skeleton's energy storage solutions

Certified

ISO 9001:2015 · ISO 14001:2015 · IATF 16949

Global Reach from the Heart of Europe

Combining German engineering & Estonian IT

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The largest and most modern supercapacitor factory in Europe

Großröhrsdorf, Germany

Industrial scale, highly automated production facility

Supercapacitor research & development center

Main production location from cells to systems

Bitterfeld-Wolfen, Germany

Curved Graphene synthesis and production

Material pilot & development plant

Solid-state material research

Berlin, Germany

Sales & application engineering

Grant & IP management

Solid-state battery development

Tallinn, Estonia

Software development

Electronics engineering

Module & system development

Backed by a Strong Investor Base – Over 200M EUR of Capital Invested

Committed to supporting the company becoming a global market leader by 2024

Marubeni

eit InnoEnergy Knowledge Innovation Community

HARJU ELEKTER

MMG MM GRUPP

FIRSTFLOOR CAPITAL

Founder of CTEK

Co-founder of adyen

Co-founder of wise

“ **Enabling carbon-neutral electrification** is a key priority for us and Skeleton Technologies fits in our portfolio perfectly. The company has **validated its competitive advantage** in **real-life applications** and has shown **strong commercial traction**. ”

Masayuki Omoto
COO, Next Generation Business Development
Marubeni Corporation

Technological Advantage Through Superior Carbon Raw Material

Backed by the largest R&D team in the industry

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Li-ion Batteries

use a chemical reaction to store energy

Slow

- Limited power density (0.5 kW/kg)
- **High energy density** (205 Wh/kg)
- Limited cycle life (<3000)
- Slow charge rate (1.5 C)
- Safety concerns

Supercapacitors

use an electric field to store energy

Fast

- **High power density** (up to 60 kW/kg)
- Limited energy density (up to 20 Wh/kg)
- Extreme cycle life (>1 million)
- Extremely fast charge rate (2000 C)
- High inherent safety

Key Enabling Technology to Power Electrification Across Industries

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A qualified supplier & system provider to industry leaders

Fuel cell power support solutions

48V active suspension

KERS / Push-to-pass

12V board net stabilization & back-up solutions

KERS for light rail

Engine start

Mild hybrid bus energy storage

Fuel cell power support solutions for rail and bus transportation

Wind turbine pitch control

Virtual inertia / Grid forming in STATCOMs

Microgrid power back-up and quality

Peak load shaving to cover short-term peak power demands

KERS for port cranes, forklifts, and elevators

Fast-charging for warehouse AGVs and shuttles

ATTABOTICS · Brush Traction (A Wabtec company) · CAF Power & Automation · Danfoss · esa · GE · Hitachi Energy · MEDCOM · KEB · ŠKODA · WRIGHT

Supercapacitors Electrifying Trams in Germany

Kinetic energy recovery reduces costs and protects infrastructure

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Skeleton Technologies supercapacitor modules will be installed in **Skoda Transportation trams** in Mannheim, Heidelberg, and Ludwigshafen in **Germany**.

The supercapacitor system **captures braking power** and **re-uses it for acceleration**, saving **30% of energy**, as well as decreasing wear on brakes. Supercapacitors also **protect infrastructure** by shaving peaks of power.

Skeleton's **advantage is very low internal resistance**, resulting in the long application lifetime due to **lowest operating temperature on the market**. The high power density of our supercapacitors **enables space** and **cost savings** compared to competing products.

Enabling Continuous Operation for Intralogistics Shuttles

Recharging in seconds along the route, no charging space required

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Attabotics, a Canadian intralogistics company, uses a **custom supercapacitor module** in its patented storage structure, enabling **85% warehouse space reduction**.

A **custom-designed super-capacitor module** powers Attabotics' automated **intralogistics shuttles**.

Compared to batteries, supercapacitors provide **3-4x the lifetime** with **zero maintenance** or the need for a charging area. The supercapacitor module utilizes opportunity charging at predetermined spots along its route, enabling **constant 24/7 operation**.

Hybrid Supercapacitor + Fuel Cell Buses

Kinetic Energy Recovery improves fuel economy and range

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36%

Fuel savings

Skeleton Technologies **supercapacitor modules** will work in a **hybrid solution** with **hydrogen fuel cells** in Wrightbus' fuel cell buses.

Supercapacitors **recuperate braking energy and re-use it for acceleration**, while reducing the stress on fuel cells and improving the vehicles' fuel economy and range.

"For hydrogen buses, Wrightbus is working with world-class leaders such as Skeleton Technologies for supercapacitors. **Supercapacitors and fuel cells are the ideal combination for better performance and lower cost of ownership**."

Jo Bamford
Chairman, Wrightbus

Current energy storage technology not without shortcomings

No single solution meets all market requirements

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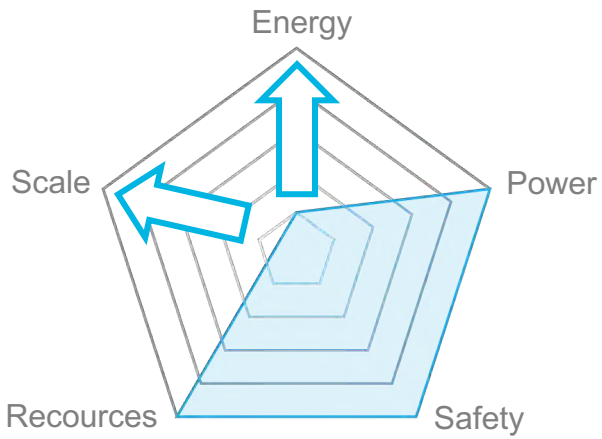

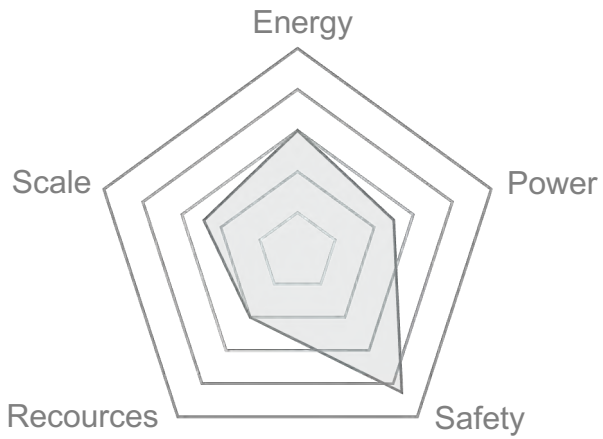

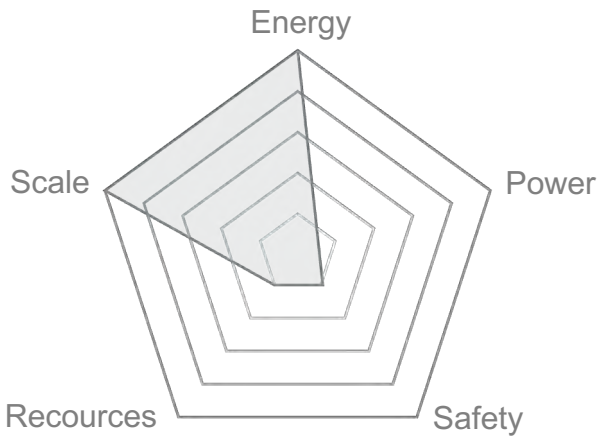

Supercapacitors

- + Energy throughput ($/kWh cycle)
- + Efficiency (cost per kW)
- + Wide temperature window
- - Low energy density
- - Very high initial cost ($/kWh)

High power batteries

- + Medium energy density
- + Medium efficiency
- + Relatively fast charging
- - Unable to meet 100k cycle requirement
- - High initial cost ($600/kWh)

High energy batteries

- + Low energy density cost (~$120/kWh)
- - Very low cycles
- - Long charging times

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Energy storage solutions

for cars & trucks

Gefördert durch Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages

Gefördert durch Freistaat SACHSEN

Transport and Automotive Product Portfolio

High-power energy storage for 12V, 48V, and HV applications

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	Low voltage		High voltage
System:	12V		400 – 800V
Product:	SkelHESS 15V	SkelMod 15V 30F-200F	HV SuperBattery pack

Protects batteries from high currents

Full efficiency even at -40 °C

>10-year lifetime

Reduction of battery content / replacement of battery

High voltage packs for high power applications (HEV/FCEV)

15 seconds charge with 40 Wh/kg on pack level

No thermal runaway or similar safety issues

New 12V applications require new energy storage solutions

New applications and regulations shift the requirements

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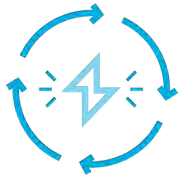
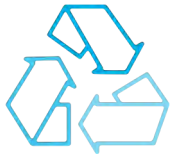
Autonomous functions: **More redundancy**

12V based autonomous functions require the 12 V on-board-net to perform well in “worst case” scenarios such as low SOC combined with low temperature. At the same time, power demands increase.



Electrification: **Higher power demand**

Electrified safety and autonomous functions such as e-braking, e-steering and image/LIDAR analysis computing require increased power.

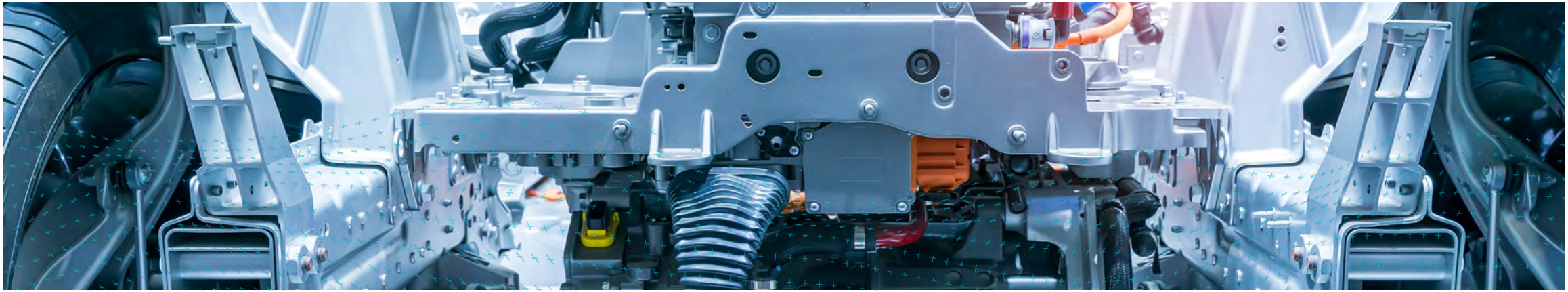


Regulations: **Recycling is in the spotlight**

New European battery directive (Regulation concerning batteries and waste batteries) will impact both lead-acid and Lithium-ion batteries. Batteries heavier than 5 kg will be treated as “industrial batteries” and face added regulation on recycling and sustainability.

Existing solutions present shortcomings

Not all requirements can be fulfilled efficiently



Lead-Acid batteries

- Toxic lead leads to regulatory issues
- Increased power demand limits lifetime
- Low temperature performance creates issues in „worst case scenarios“ for safety critical systems

LFP batteries

- High power demand leads to high weight
- High weight leads to increased recycling requirements in EU battery directive
- Low temperature performance raises safety concerns at < -10°C

BEV HV-12V DC/DC converter

- Redundancy requires 2 DC/DC converters
- Fast reacting DC/DC converters are expensive

12V energy storage solutions

Most optimized solution for 12V board net applications

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Problems to solve:

- Power density at < -5°C
- Recyclability

Our solution:

SkelHESS 15V - **SkelMod 15V 30F-200F + LFP Li-Ion**

- **-45%** weight*
- **-55%** volume*
- **25x** higher power density*
- Lasts the **entire lifetime** of the vehicle
- Peak power available at **-40°C**
- **No Lithium / Cobalt**

*SkelHESS 15V compared to 12V LFP Li-Ion battery

12V energy storage solutions

Most optimized solution for 12V board net applications

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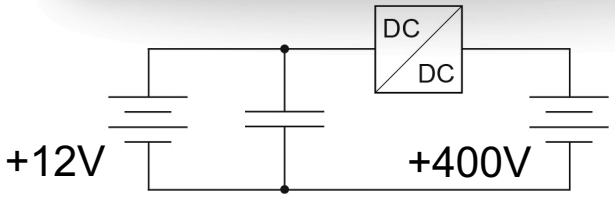
SkelHESS 15V –

SkelMod 15V 30-200F + LFP Li-Ion

LFP + battery

Complete energy storage system optimized to deliver both **peak power and high usable energy** ideal for low voltage board net with **single HV storage.**
The most compact packaging and competitive pricing on the market.

- Based on the SkelMod 15V 200F in direct parallel connection to LFP battery
- **20Ah** battery capacity
- 1s power **7kW (between 9-15V),** battery current reduction by **over 75%**
- **Increase energy storage lifetime to over 15 years**
- **45% less weight** and **55% less volume** compared to LFP battery
- Strong reliability and **best temperature tolerance from -40 to +65 °C**
- Best transition **from lead-acid batteries**



Simplified boardnet architecture of an electrified vehicle

12V energy storage solutions

Most optimized solution for 12V board net applications

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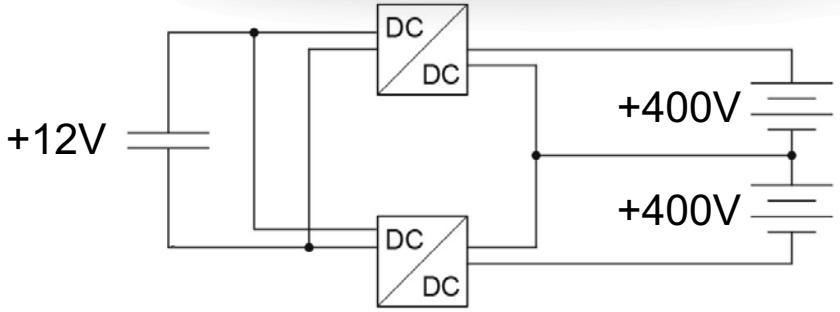
SkelMod 15V 30-200F –
stand alone solution

The 15V power module fulfills the demand of high power 12V loads in the most compact package and at a lower cost compared to an oversized Li-ion battery pack. **Ideal solution for low voltage peak power supply in systems with redundant HV storages.**

- Performance based on the SkelMod 15V 200F:
- Ready to use replacement in applications with redundant HV storage
- 1s power **7kW (between 9-15V)** to cover any high-power demand
- Usable with a battery to **minimize its loads, capacity and extend its lifetime**
- Best in-class usable energy at **4Wh (between 9-15V)**
- Most compact: only **0.7L** and **1kg**
- **1+ million cycles** and **lifetime 15+ years**
- Strong reliability and **best temperature tolerance from -40 to +65 °C**



Simplified boardnet architecture of an electrified vehicle with two high-voltage battery packs

12V energy storage solutions

End customer perspective

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Autonomous functions

available in cold weather, higher driving speeds and other extreme conditions

No need for

exchanging 12 V battery over vehicle lifetime

High Voltage energy storage: Challenges for xEVs

FCEVs, HEVs and performance BEVs require high power

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Power load

Braking Energy recuperation and acceleration of heavy cars requires high power

Power / Energy ratio

For FCEVs and HEVs, the battery size is < 2kWh, but the power rating is >100 kW, requiring >50C charge/discharge rate

Lifetime

Many cycles during daily use decrease LIB lifetime

Safety

LIBs require extensive safety measures

HV energy storage solutions

SuperBattery Pack – The best of both ultracapacitor and battery worlds

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Problem to solve:

Batteries do not **last for the vehicle lifetime** when faced with **extreme peak power loads** and thus need to be oversized

Our Superbattery solution:

HV SuperBattery pack

- **65 Wh/L energy density**
- **Peak power 200kW+**
- **-40% weight and volume***
- **No thermal runaway**
- **50k+ cycles,**
  no power limitation or lifetime compromise
- **Low cooling requirements**
  due to low internal resistance

*compared to Lithium-Ion battery

HV energy storage solutions

SuperBattery Pack – The best of both ultracapacitor and battery worlds

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HV SuperBattery pack –
the best of energy storage world

Optimal high power energy storage for hybrid and electric powertrains in **the most compact package** and at **lower cost** compared to oversized Li-ion battery pack.

- Based on 21700 form factor cell
- **400V** pack with **1.84 kWh** and **200+ kW** peak power within 32kg and 20.8L
- **50k+ full cycles** fulfills the requirements of every hybrid application
- **Safe operation down to -30°C** without the impact on the lifetime
- Ideal fit as an additional power storage for FCEV, HEV
- Customized pack design up to **1500V**

HV energy storage solutions

End-customer perspective

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Thank you!

For more information contact us:

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