Electric bike with a mileage of 60 km and an electric drive power of 300 W and consumption of 20 Wh/km

Group presentation

Members: Neti Rucksalam, Hugo García Tovar, Md Nahid Hossain Khan and Sebastian Hillert

29.01.2020

Lehrstuhl für Elektrochemische Energiewandlung und Speichersystemtechnik

Stromrichtertechnik und Elektrische Antriebe

RWTH AACHEN UNIVERSITY

Outline

- Introduction
- Goals and strategies
- Choosing an appropriate battery
- Comparison of battery cells
- Battery pack design
- Charging and lifetime calculation
- Thermal Management System
- Battery Management System (BMS)
- Cost analysis
- Conclusion

Goals and Strategies

- Goals
  - To analyze and design the battery storage system for E-bike by the following conditions
    - A mileage of 60 km
    - An electric drive power of 300 W
    - Energy consumption of 20 Wh/km
- Assumption
  - Charging once a week (total energy consumption 1200 Wh)
  - DOD = 75%

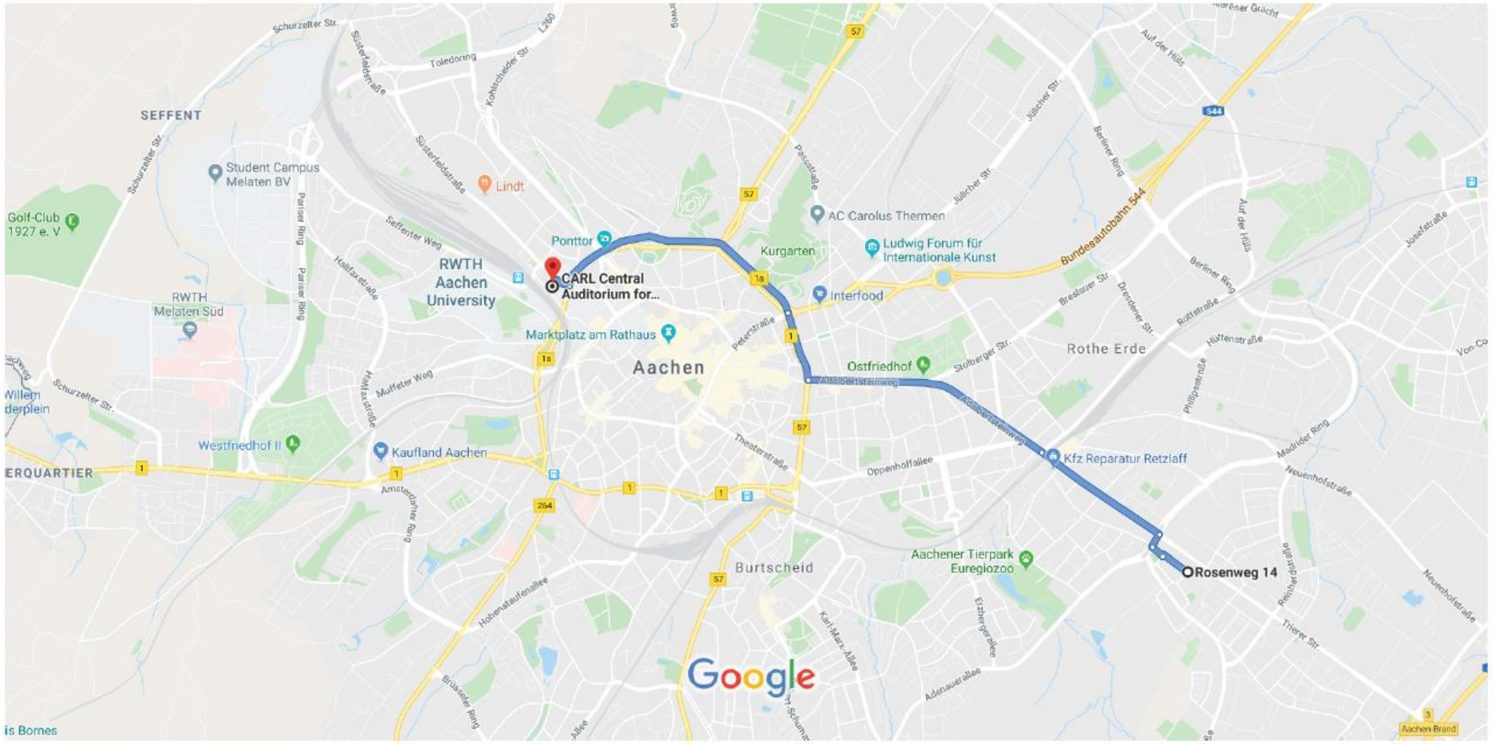
E-bike usage

- Daily cycling route from my apartment to the university (C.A.R.L building)
- From Monday to Friday: 10 Km/day (a round trip)
- Saturday and Sunday: 5 Km/day
- Approximately: 60 Km/week

Google Maps

Rosenweg 14, 52078 Aachen to C.A.R.L. Central Auditorium for Research and Learning

Bicycle 5.0 km, 18 min



Map data ©2019 GeoBasis-DE/BKG (©2009) 500 m

Electric bike with a mileage of 60 km and an electric drive power of 300 W and consumption of 20 Wh/km

Typical Characteristics of Battery Types Used in Pedelec

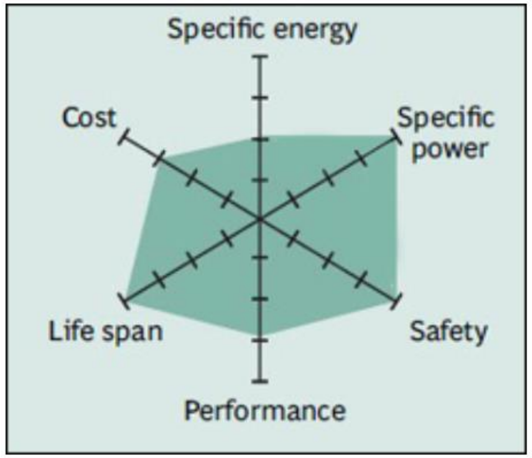
Battery type	Energy density in Wh/kg	Components/ ingredients	Lifespan/maximum no. of charge cycles depending on use	Advantages and disadvantages
Lithium-ion ($LiMn_2O_4$)	110 - 130	lithium manganese copper aluminium graphite	Up to 1,000 charge cycles	+ low self-discharge + high level of stability and safety + low costs
Lithium-ion ($LiFePO_4$)	110 - 130	lithium iron phosphate copper aluminium graphite	over 1,000 charge cycles possible	+ low self-discharge + very high level of stability and safety + can be charged quickly + long lifespan + good raw material availability
Lithium-ion ($Li(NixCoyMnz)O_2$)	140 - 160	lithium cobalt nickel manganese copper aluminium graphite	over 1,000 charge cycles possible	+ low self-discharge + high energy density + long lifespan
Lithiumionen ($LiCoO_2$)	140 - 160	lithium cobalt nickel copper aluminium graphite	up to 1,000 charge cycles possible	+ low self-discharge + high energy density - high costs
Nickel-metal hydride (NiMH)	55 - 100	nickel iron cobalt rare earths (lanthanum, cerium, neodymium, praseodymium)	up to 1,000 charge cycles possible	+ very high level of stability and safety + low costs - Very high self-discharge rate (approx. 20% per month) - low energy density

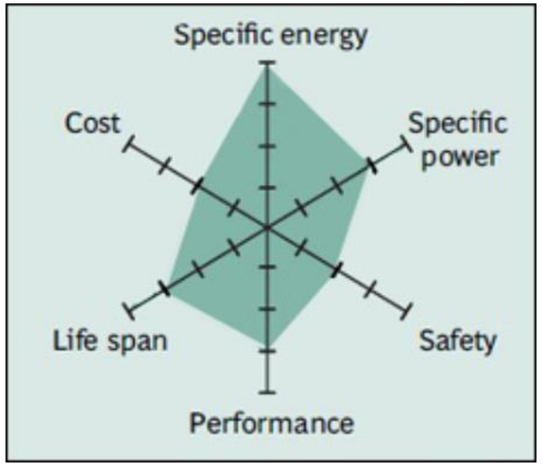
Battery types used in pedelecs [1]

Electric bike with a mileage of 60 km and an electric drive power of 300 W and consumption of 20 Wh/km

Comparison of LFP and NMC

	$LiFePO_4$ (LFP)	LiNiMnCoO2 (NMC)
Voltages	3.20, 3.30V nominal	3.60V, 3.70V nominal
Specific energy (capacity)	90–120Wh/kg	150–220Wh/kg
Cycle life	2000 and higher (related to DOD, temperature)	1000–2000 (related to DOD, temperature)
Thermal runaway	270°C (518°F) Very safe battery even if fully charged	210°C (410°F) typical. High charge promotes thermal runaway
Cost	~$580 per kWh	~$420 per kWh





Comparison of LFP and MMC [2]

Battery Cells Available on Market

Model	Norminal Voltage (V)	Max Continous Discharge Current	Nominal Capacity
14430	3.2V	800mA(2C)	400mAh
14430	3.2V	800mA(2C)	400mAh
14505	3.2V	600mA(1C)	600mAh
17335/CR123A	3.2V	450mA(1C)	450mAh
18500	3.2V	800mA(1C)	800mAh
18650 (A123 brand) APR18650m1-B	3.3V	30A(~27C)	1100mAh
18650	3.2V	49.5A(45C)	1100mAh
18650	3.2V	5A	1500mAh
26650 (A123 brand) ANR26650m1B	3.3V	50A(20C)	2500mAh
26650	3.2V	10A	3300mAh
32600	3.2V	60A	2600mAh
32650 Discontinued, Replaced by 32700	3.2V	15A(3C)	5000mAh
32700	3.2V	18A(3C)	6000mAh
38120S	3.2V	30A(3C)	10000mAh
42120E	3.2V	20A(2C)	10000mAh
42120	3.2V	60A(5C)	12000mAh
40152S	3.2V	75A(5C)	15000mAh

Battery cells available on market [3]

LiFePO4 32700 Rechargeable Cell: 3.2V 6000 mAh 19.2Wh - UN 38.3 Passed -

Your Price: $9.50

In Stock

Product ID # 11895
Part Number: LFP-32700

Product Options

Tab: LFP-32700: No Tabs(N)

Quantity: 1 Buy

Add to a new shopping list

Email this page to a friend

Quantity Discounts

Quantity	Amount
5 to 20	$9.21
21 to 50	$9.02
51 to 100	$8.83
101 or more	$8.55

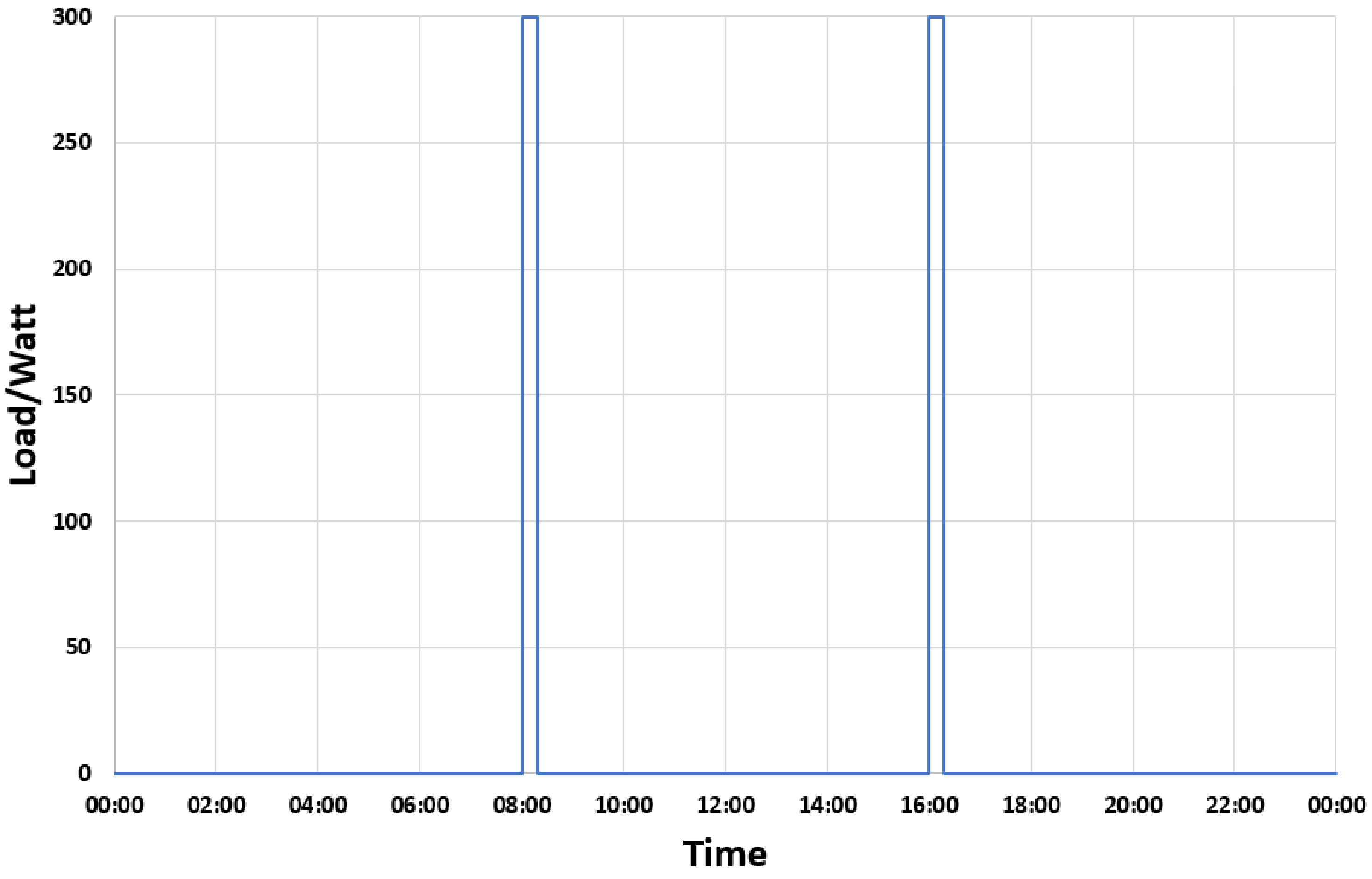
Selected battery cell [4]

Comparison of LFP (cylinder cells)

Model	price per cell ($)	Dia. (mm)	Height (mm)	Weight (g)	Voltage	Ah	Wh	Number of cell to achieve 1600 Wh	cost total ($)	Total weight (Kg) "Only battery	Total volume (Litre) "Only battery cell"
14430	1.45	14.0	43.4	17	3.2	0.4	1.28	1250	1812.5	21.3	8.35
14505	1.75	14.0	50.3	19.8	3.2	0.6	1.92	834	1459.5	16.5	6.46
18650	3.37	18.3	65.0	38	3.2	1.5	4.8	334	1125.6	12.7	5.71
26650	6.75	26.2	65.7	90	3.2	3.3	10.56	152	1026.0	13.7	5.39
32600P	12.59	32.0	60.0	108	3.2	2.6	8.32	193	2429.9	20.8	9.32
32700	8.83	32.0	70.5	141	3.2	6	19.2	84	741.7	11.8	4.76
38120S	23.37	38.0	120.0	330	3.2	10	32	50	1168.5	16.5	6.81
42120E	37.14	42.0	120.0	390	3.2	10	32	50	1857.0	19.5	8.32
42120	49.87	42.0	120.0	400	3.2	12	38.4	42	2094.5	16.8	6.99
40152S	37.95	40.7	151.5	480	3.2	15	48	34	1290.3	16.3	6.70

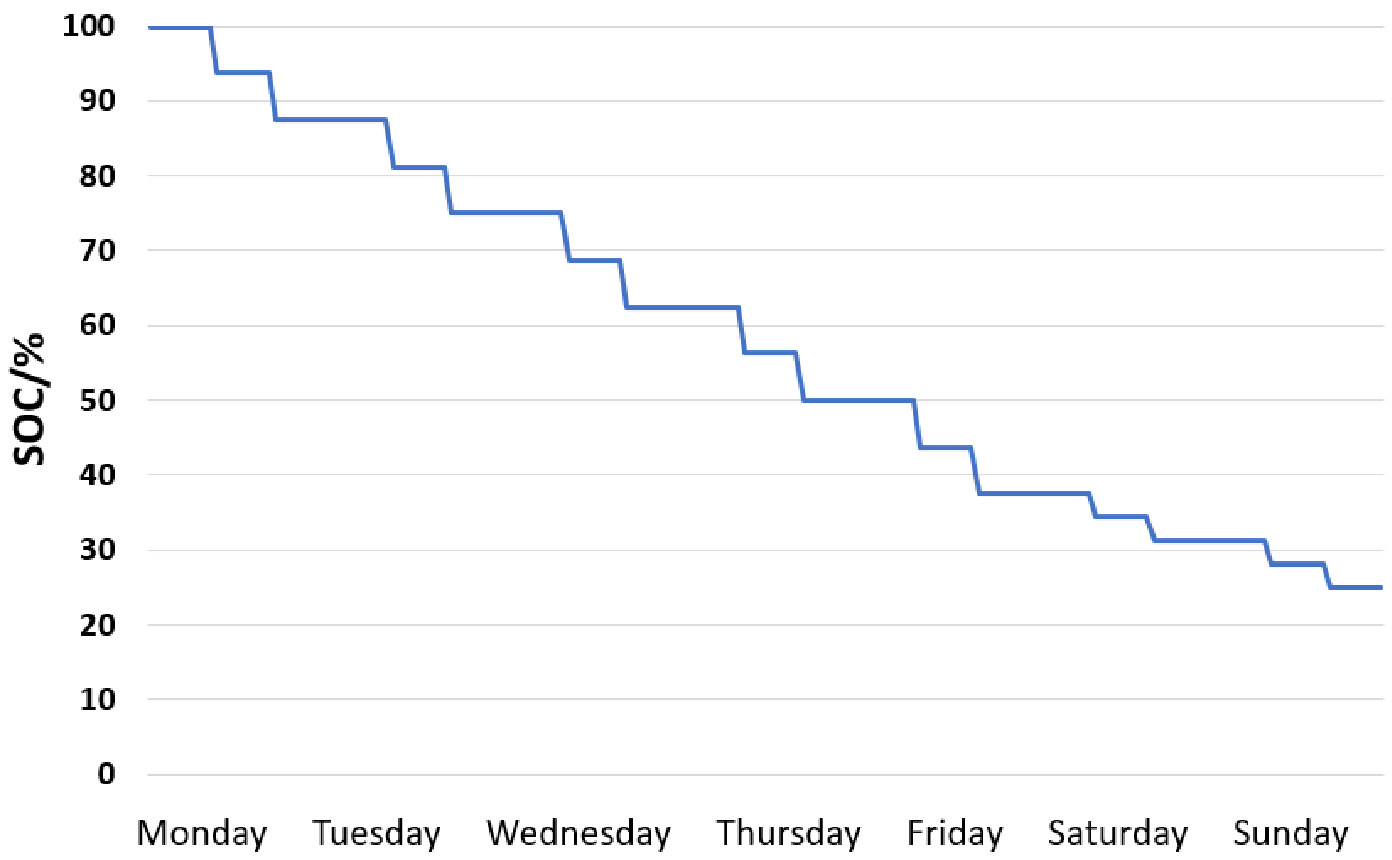
Note: Consider only cell with lifecycle ≥ 2000 times

Load Profile - Daily



Electric bike with a mileage of 60 km and an electric drive power of 300 W and consumption of 20 Wh/km

State of Charge - Weekly

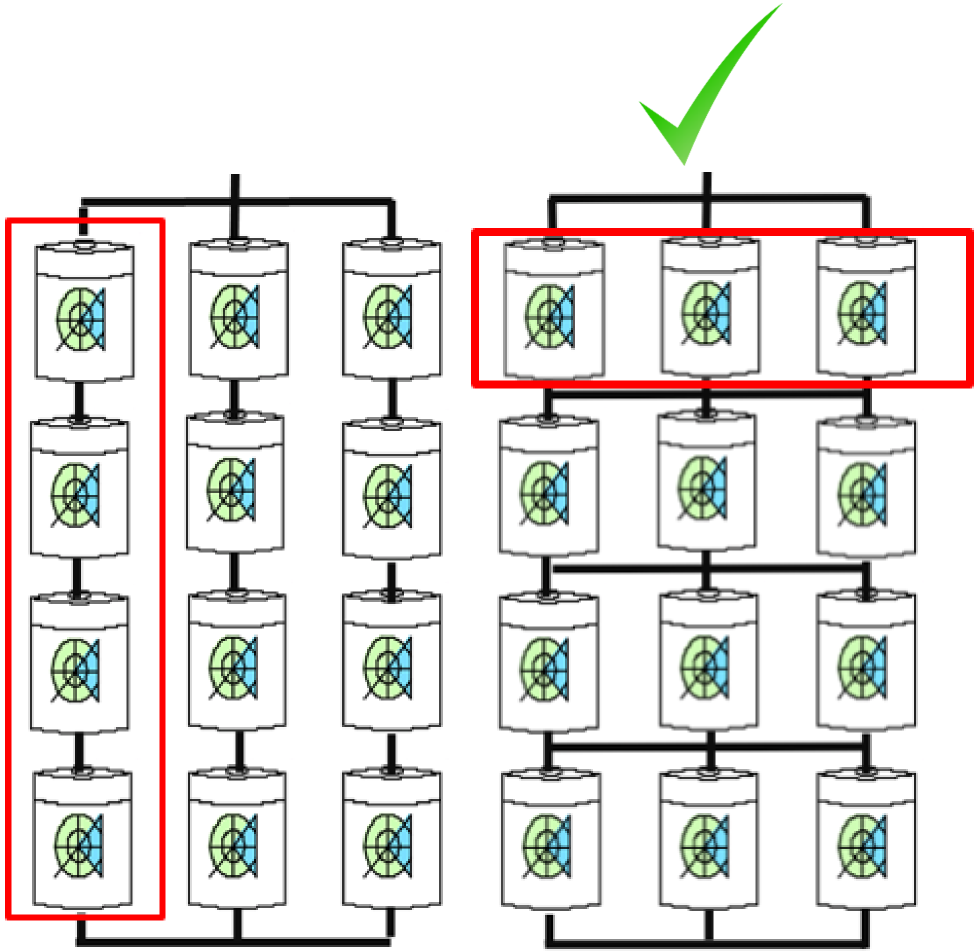


Electric bike with a mileage of 60 km and an electric drive power of 300 W and consumption of 20 Wh/km

Battery Pack Design

- Selected battery: **LiFePO4 32700**
  - Nominal Voltage: $U_N = 3.2V$
  - Nominal Capacity: $C_N = 6000mAh$
    - ➔ Energy per cell: $E_{cell} = U_N * C_N = 19.2\ Wh$
    - ➔ DOD = 75% ; η_{mec} = 90%
    - ➔ Pack Energy: $E_{bat} = 60km \cdot 20\frac{Wh}{km} \cdot \frac{1}{DOD} \cdot \frac{1}{\eta_{mec}} = \mathbf{1778Wh}$
    - ➔ Total number of cells: $n = \frac{E_{bat}}{E_{cell}} = \frac{1778Wh}{19.2Wh} = 93 \rightarrow \mathbf{96\ cells}$

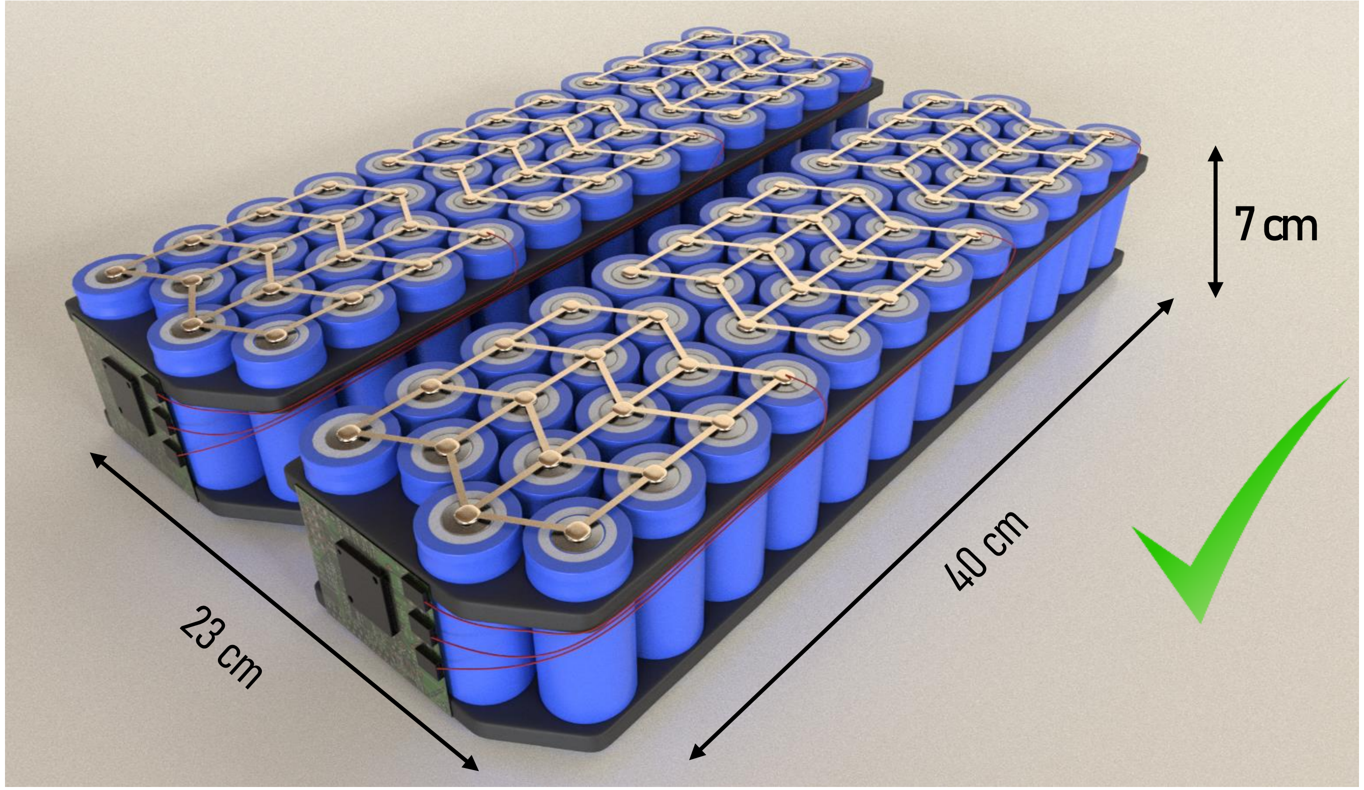
	Cell	Module
Cells in series [#]	1	8
Cells in parallel [#]	1	12
Capacity [Ah]	6	72
Voltage [V]	3,2	25,6
Energy [Wh]	19,2	1843,2

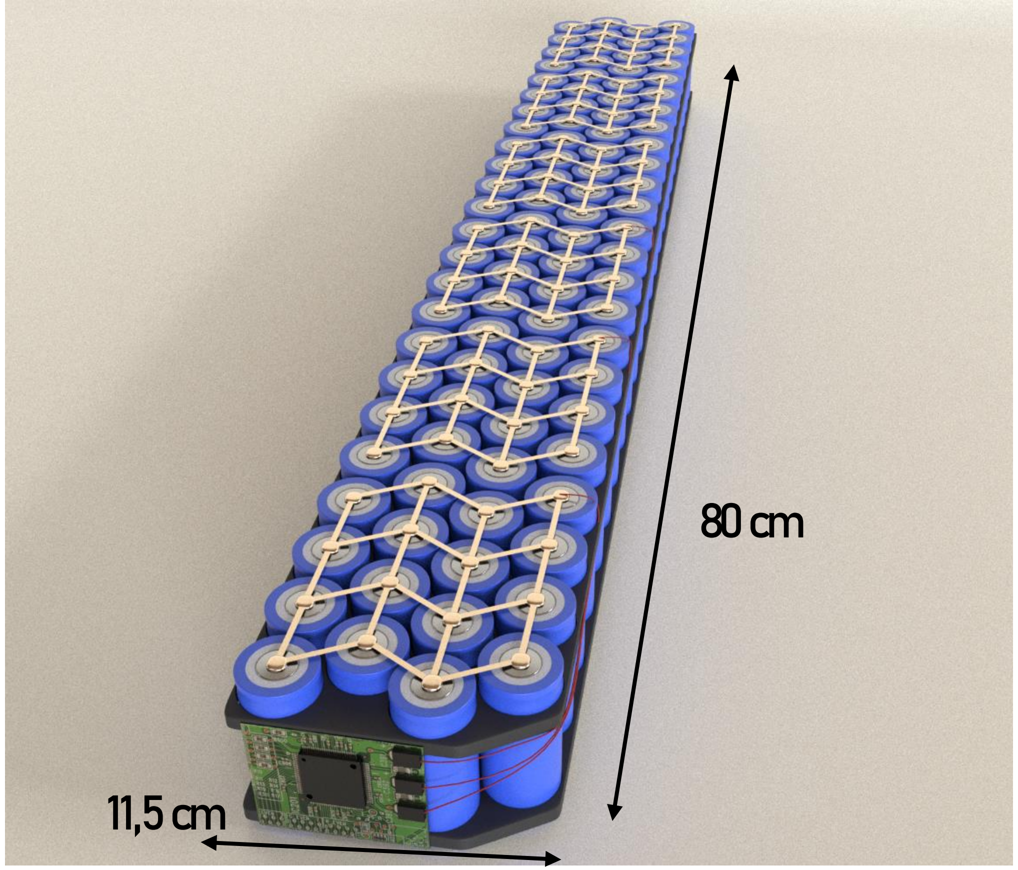


Types of cell connection [5]

Battery Pack Design – Dimensions and Arrangement

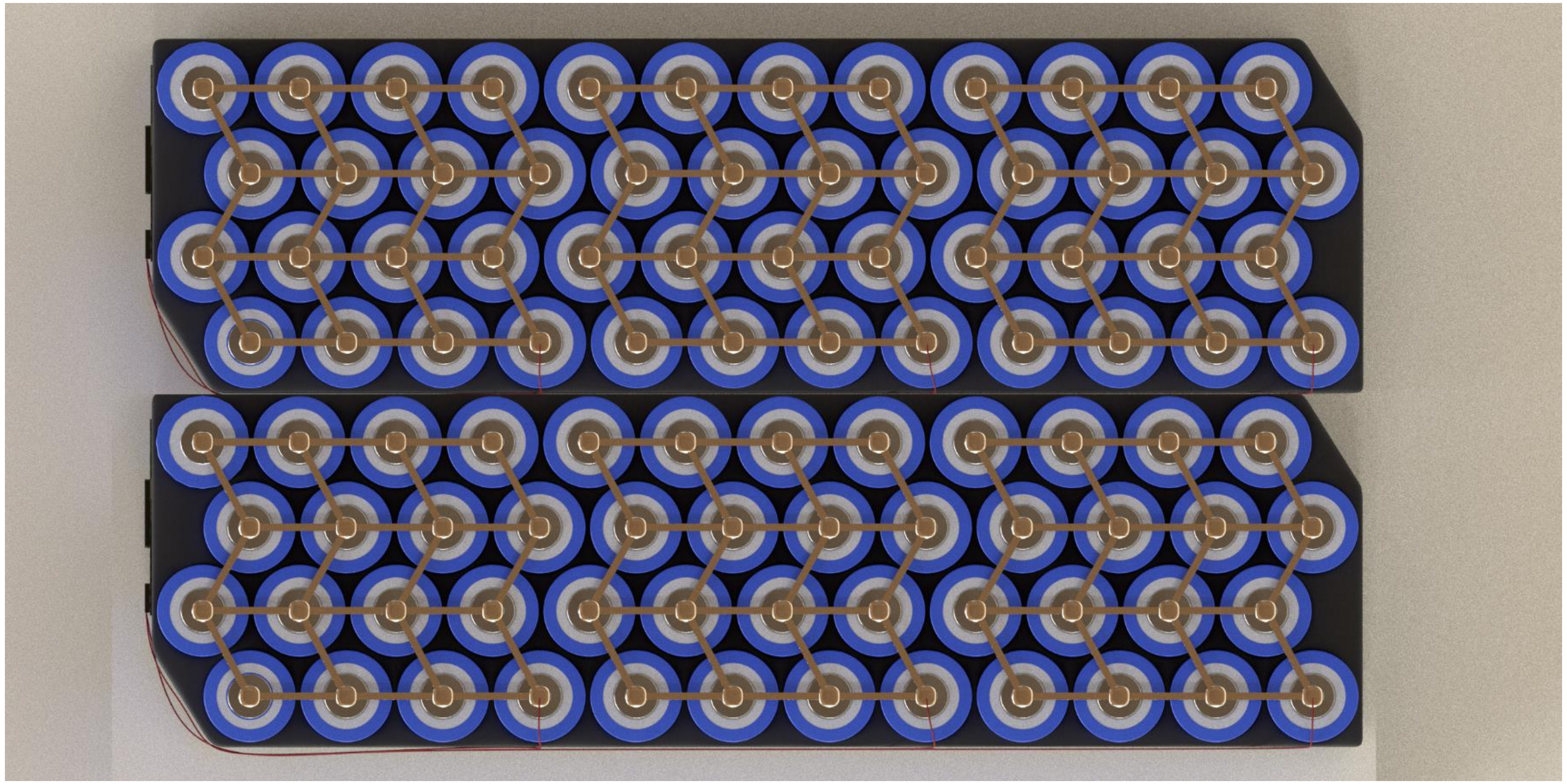
- The battery pack consists on a total of 96 cells
  - Dimensions of each cell: 3,2 x 7,5 cm (DxH)
  - Two possible ways of arrangement

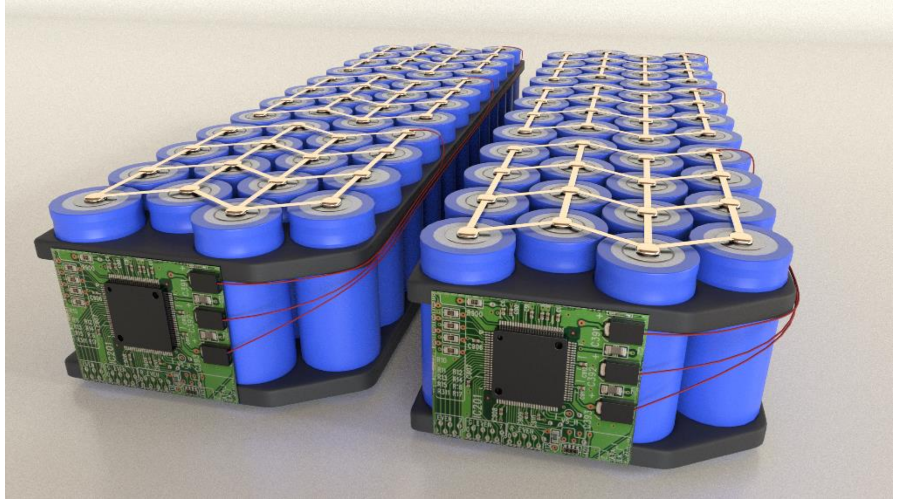


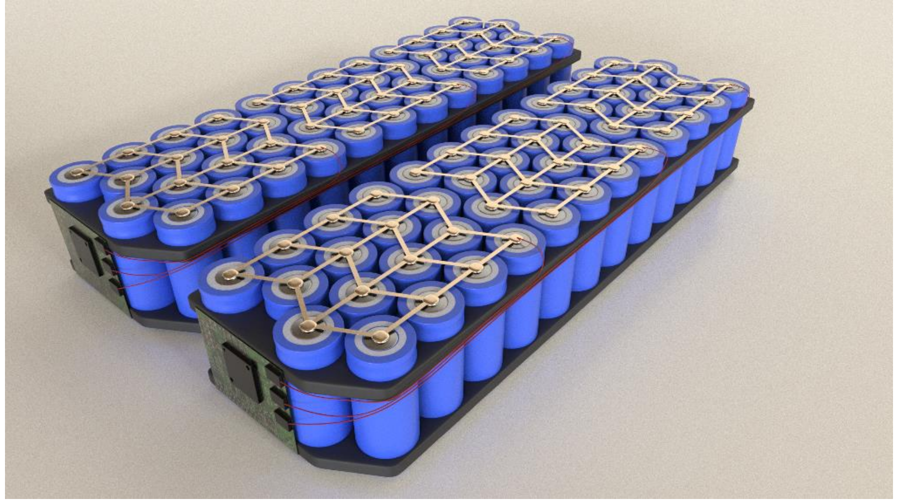


Battery Pack Design – Dimensions and Arrangement

- Hexagonal packing to optimize spacing



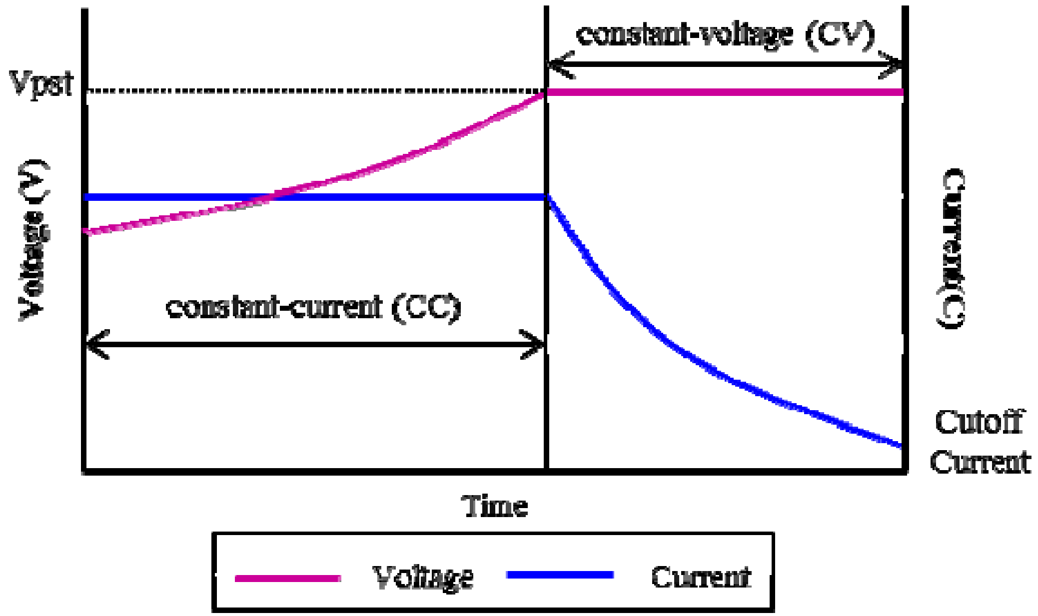




Charging Condition

- $C = 6\ Ah$; $I_{cell\_charge\_max} = 0{,}5C = 3\ A$

- Standard Charge: CC-CV
  - 1st stage: Constant current at 0.2C
    - $I_{cell\_charge} = 0{,}2 \cdot 6 = 1{,}2\ A$
    - $I_{pack\_charge} = I_{cell\_charge} \cdot n_{parallel} = 1{,}2 * 12 = 14{,}4\ A$
  - 2nd stage: Constant voltage at 3.65V until:
    - $I_{cell\_charge} = 60\ mA$
    - $I_{pack\_charge} = 0{,}06 * 12 = 0{,}72\ A$



CC-CV Charging [6]

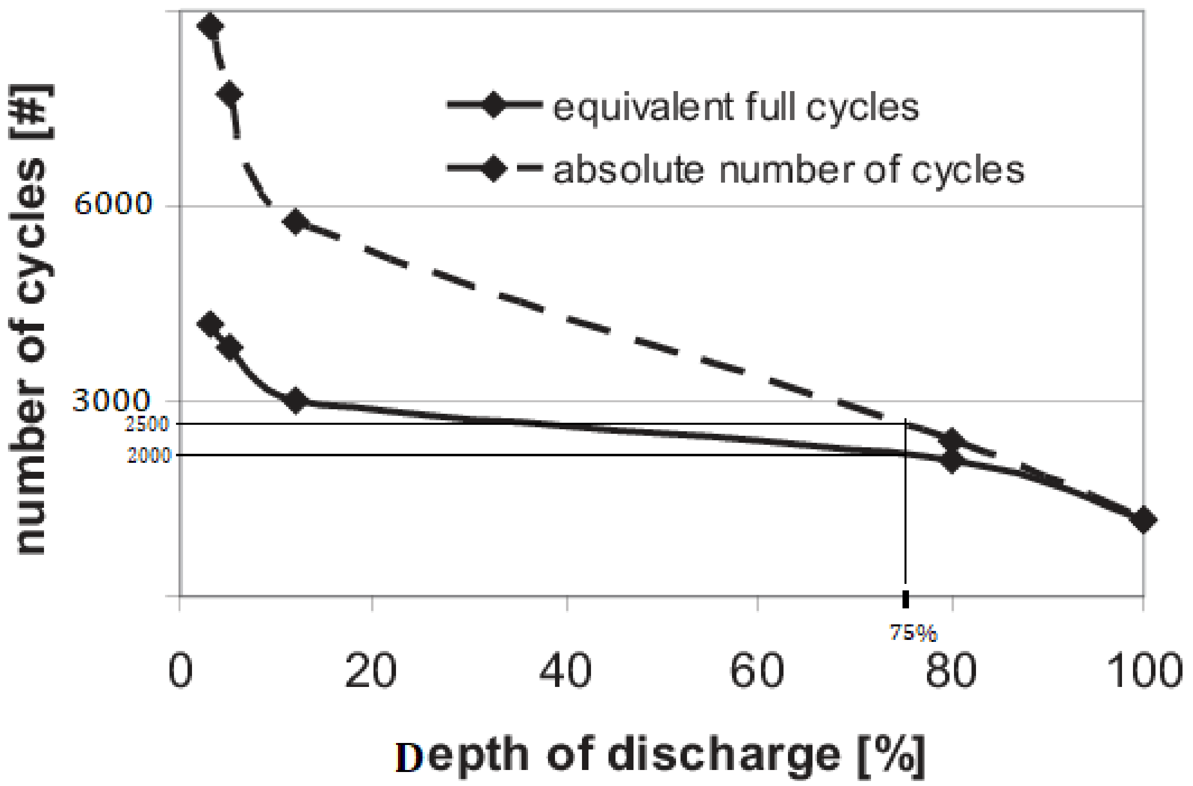
- $P_{charge,max} = I_{cell\_charge} \cdot U \cdot n_{cell} = 1{,}2 * 3{,}65 * 96 = 420{,}48\ W$

Lifetime

- Facts:
  - DOD: 75 %
  - Charging once a week

- Number of cycles before notably degrading:
  - Cycles: 2500
  - Equivalent full cycles: 2000 (data sheet)

- Lifetime (neglecting calenderic ageing):
  - Minimum: **38,5 years**
  - Maximum: 48,1 years



Relation between cycles and aquivalent full cycles [7]

Necessity of Thermal Management System

- Ambient temperature, internal short circuit, and overcharging cause the battery pack to overheat
- Cooling system helps to maintain homogenous temperature and avoid thermal runway
- In winter/low temperature, it is necessary to heat the battery to avoid lithium plating

Types of Cooling System

- Types of cooling system:

  - Water cooling system
    - Water-Glycol cooling system
    - Water cooling system

    - Pros & cons
      - Expensive
      - Requires Maintenance

  - Air cooling system

    - Pros & cons
      - Inexpensive
      - Does not require maintenance

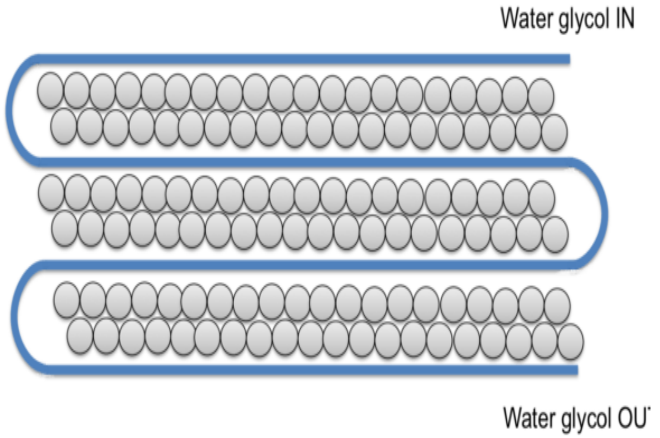


Fig: Water-Glycol cooling system [8]

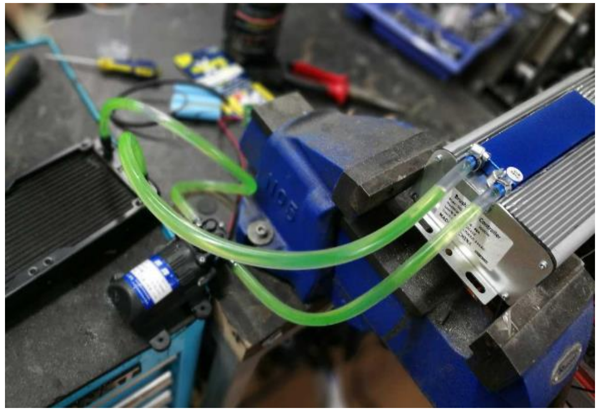


Fig: Water cooling system [9]

Cooling & Heating

- We can keep our battery cool through the following steps:
  - Aluminum hard case for battery pack
  - Mounting batteries on panniers
  - Passive air-cooling system
  - Split grill and air intake at the front of bike

- To keep the battery pack warm during extreme low temperature, the battery pack can be covered by a thermal cloak

Fig: Battery pack mounted on aluminum hard case

Fig: Battery pack mounted on panniers

Battery Management System (BMS)

- **7S~10S Lithium ion battery smart protection BMS**
  - Dimensions: 140*60*20 mm
  - 20 A constant discharge current and charging current
  - **Price**: 29 euros.

- **Protection functions:**
  - Overcharge Protection
  - Over-discharge protection
  - Short circuit protection
  - Temperature Controlling Circuit

- Real time monitoring is possible through Android/IOS app connected via Bluetooth 4.0

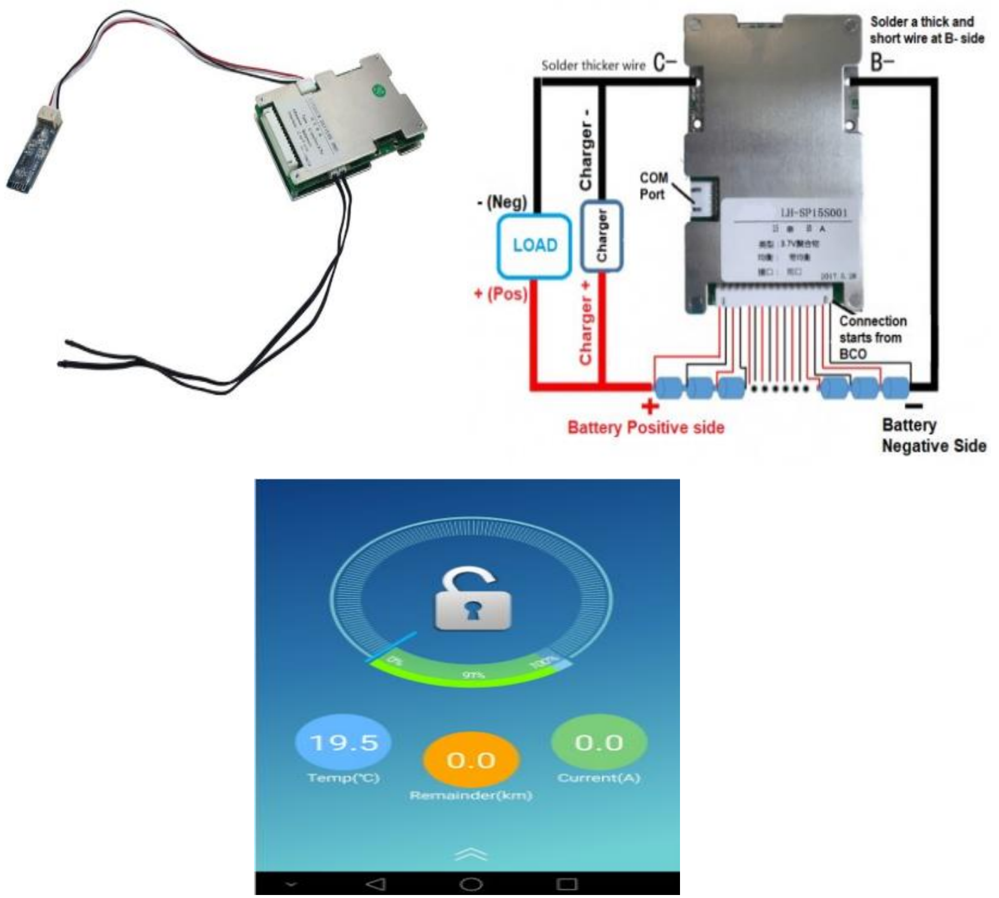


Fig: Smart BMS 7S~10S 20A with Bluetooth app [10]

Cost Analysis

- Mileage of 60 km/week
- Prizes:
  - 1kWh = 31,94ct
  - 1l fuel = 143,6ct
- Energy Consumption
  - 20Wh/km
  - scooter = 2,5l/100km
  - car = 7,8l/100km
- Operating cost per year
  - E-Bike = 19.92€
  - 112€ (scooter], ~350€ (car)

92€/yr

- Battery cost breakdown:
  - Cost for cells = 847.68€
  - Cost of BMS = 29€
  - Aluminium Housing ≈ 100€
- Investment cost = 976.68€

Comparison with a Motorized Bike

Category	Electric Bike	Scooter (Vespa)
Speed	25km/h – 50km/h “Permit” M required	50km/h Permit AM required
Power source	Electric	Gasoline
Power cost	~ 64ct / 100km	~ 3,60€ / 100km
Purchase cost	2.400€	≥ 3600€
Environmental effects	▪ Zero Emission (Assumption green energy) ▪ Quiet engine	▪ Emission of CO_x, NO_x and other substances ▪ Noticeable engine noise

„Amortization“ after 24yrs

Electric bike with a mileage of 60 km and an electric drive power of 300 W and consumption of 20 Wh/km

Conclusion

- E-bike battery with
  - 96 cells in total
    - 8 in series
    - 12 in parallel
  - Energy per cell: 19.2Wh
  - Energy of the battery: 1843.2Wh
- Economical Viability
  - „Amortization“ after 24 yrs
  - Liftetime savings of 3,542€ @ 92€/yr

References

1. https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/hgp_electric_bikes_get_things_rolling.pdf
2. https://batteryuniversity.com/learn/article/types_of_lithium_ion
3. https://www.batteryspace.com/LiFePO4-Cylindrical-Single-Cells.aspx
4. https://www.batteryspace.com/lifepo4-32700-rechargeable-cell-3-2v-6000-mah-19-2wh---un-38-3-passed.aspx
5. https://www.utdallas.edu/essl/projects/battery-pack-characterization-investigator-l-guo/
6. https://www.semanticscholar.org/paper/Wireless-lithium-ion-battery-charging-platform-with-Kim-Kim/5d5732d63a6b00de9d3ba3d946f3c285ba423aec
7. https://www.researchgate.net/figure/Example-for-a-Woehler-Curve-for-batteries-Cycle-lifetime-for-a-NiMH-battery-is-shown-as-a_fig4_299579838
8. https://avidtp.com/what-is-the-best-cooling-system-for-electric-vehicle-battery-packs/
9. https://evnerds.com/ev-album/your-ebike/ebike-cooling/
10. https://bmsbattery.com/home/1081-18431-smart-bms-7s10s-20a-with-blue-tooth-app.html#/16-battery_type-lifepo4/105-cells_in_series-8