LCA Forum
Zürich 2018

Future battery storage technologies – performance prospects and LCAs of batteries suited for stationary applications

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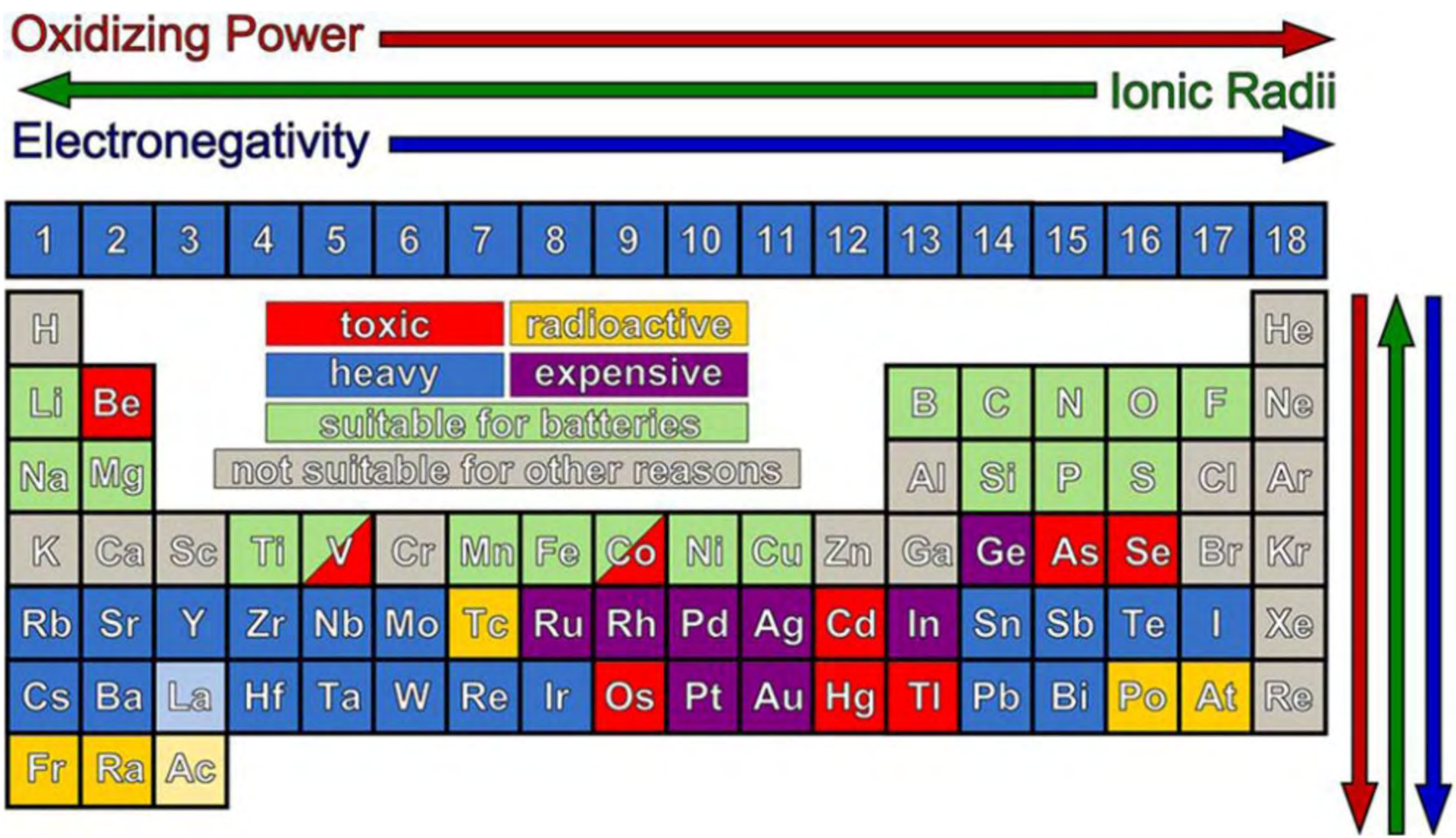
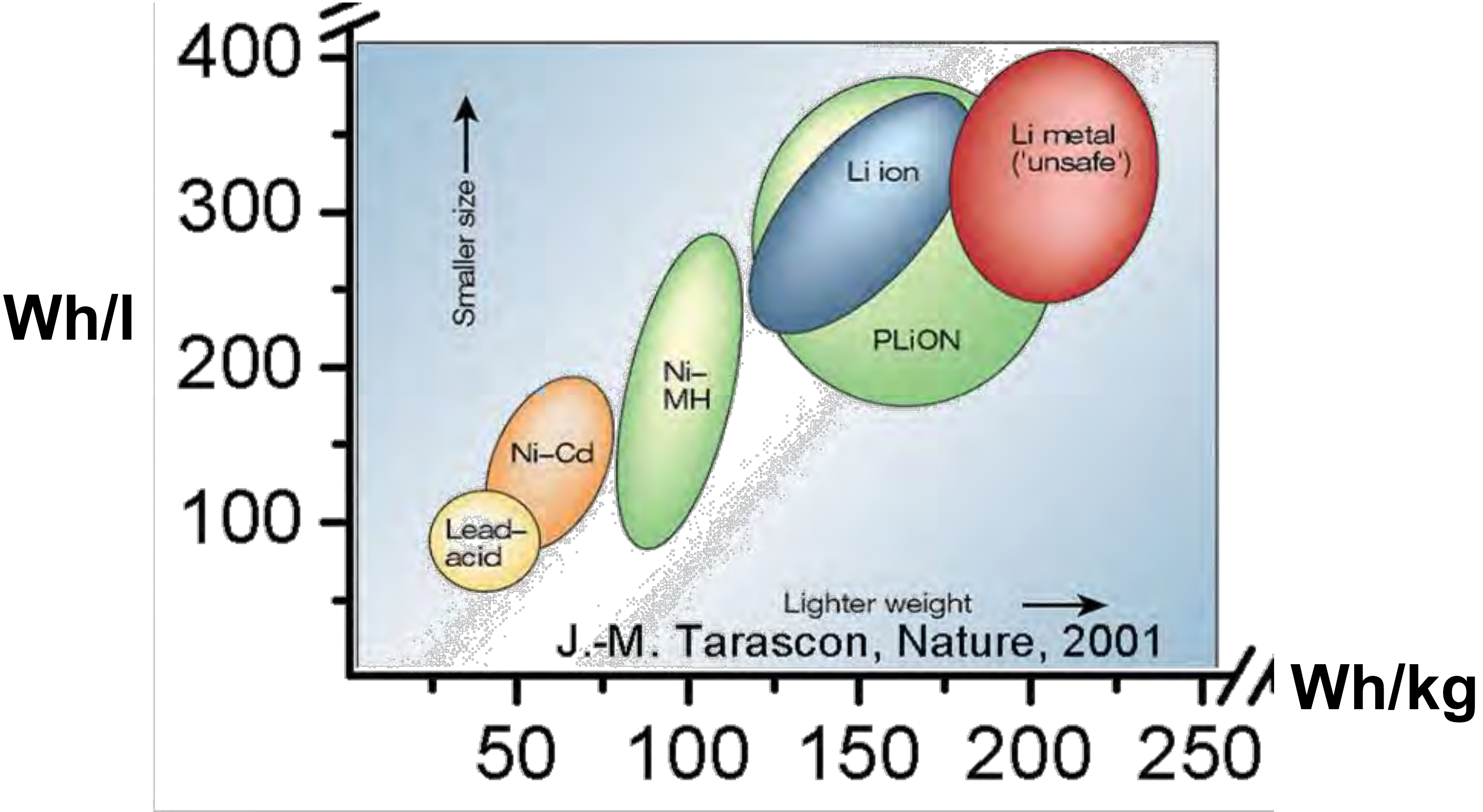
"The_School_of_Athens“ by Raphael (Vatikan)

"The_School_of_Athens" by Raphael (Vatikan)

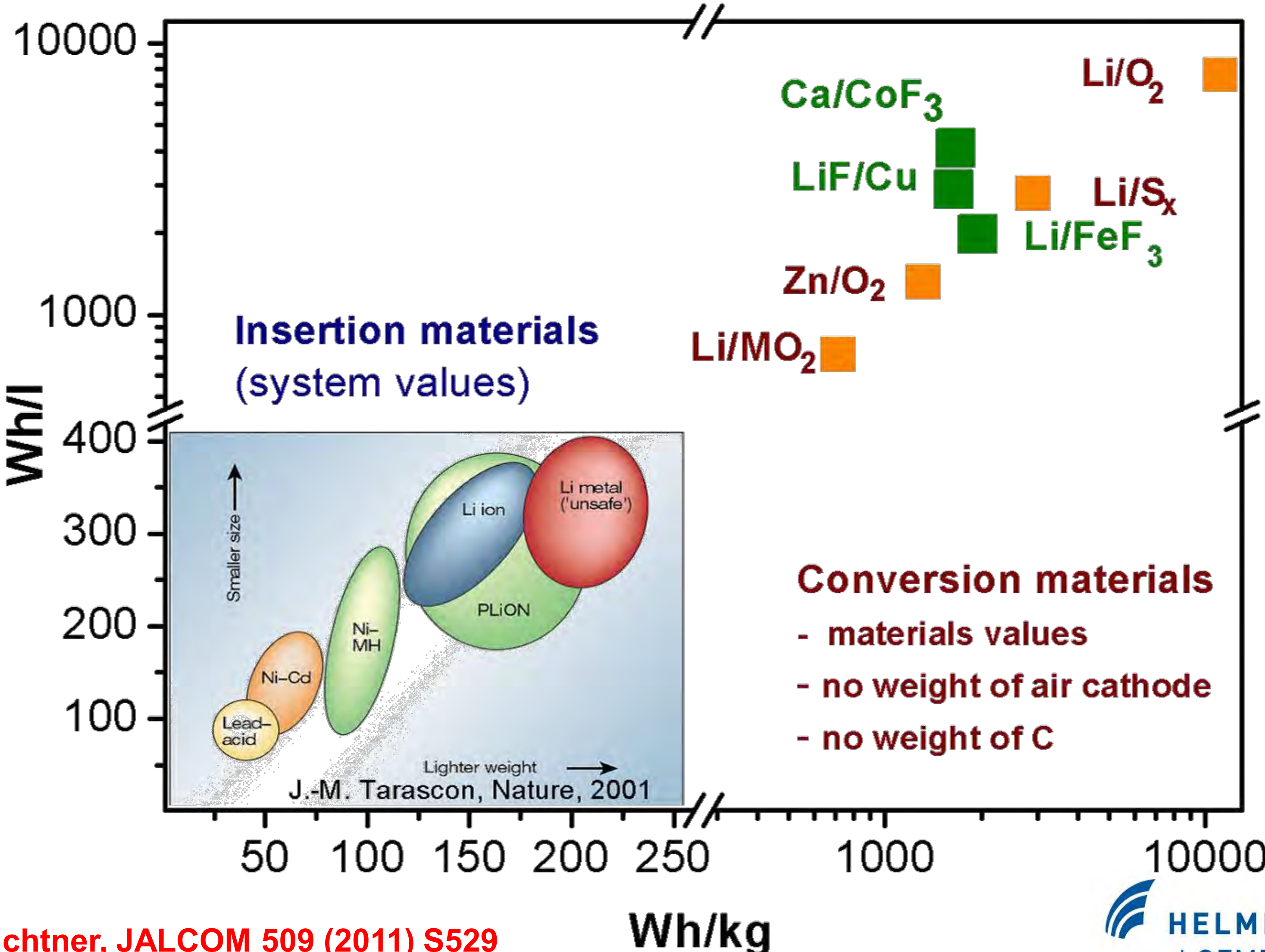


Source: Chaofeng Liu,Zachary G. Neale,Guozhong Cao: Understanding electrochemical potentials of cathode materials in rechargeable batteries. Materials Today, Elsevier, March 2016

Present Battery Systems



Future Battery Systems



M. Fichtner, JALCOM 509 (2011) S529

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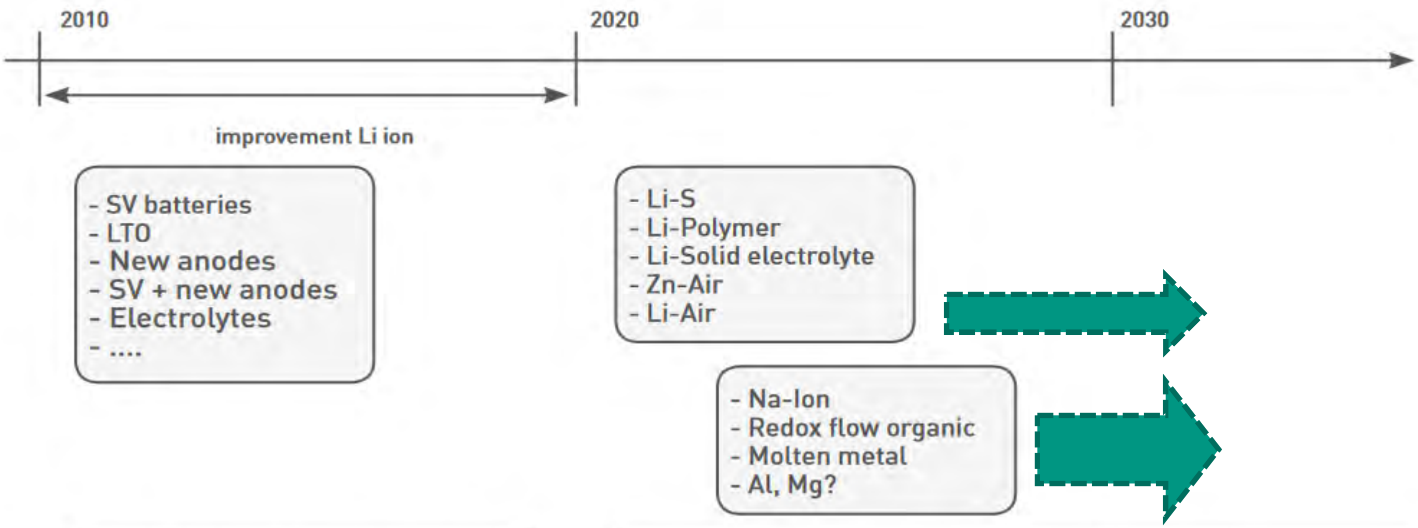


New material needs by 2020	
LiMnNi(Co) oxides $LiNiPO_4$ $LiCoPO_4$ $LiVPO_4$ + others	class cathode materials 4,5 - 5V
LTO C/Metal composites Si, Sn-intermetallics	class high capacity nem anodes
additives electrolyte SV electrolytes	stable electrolytes

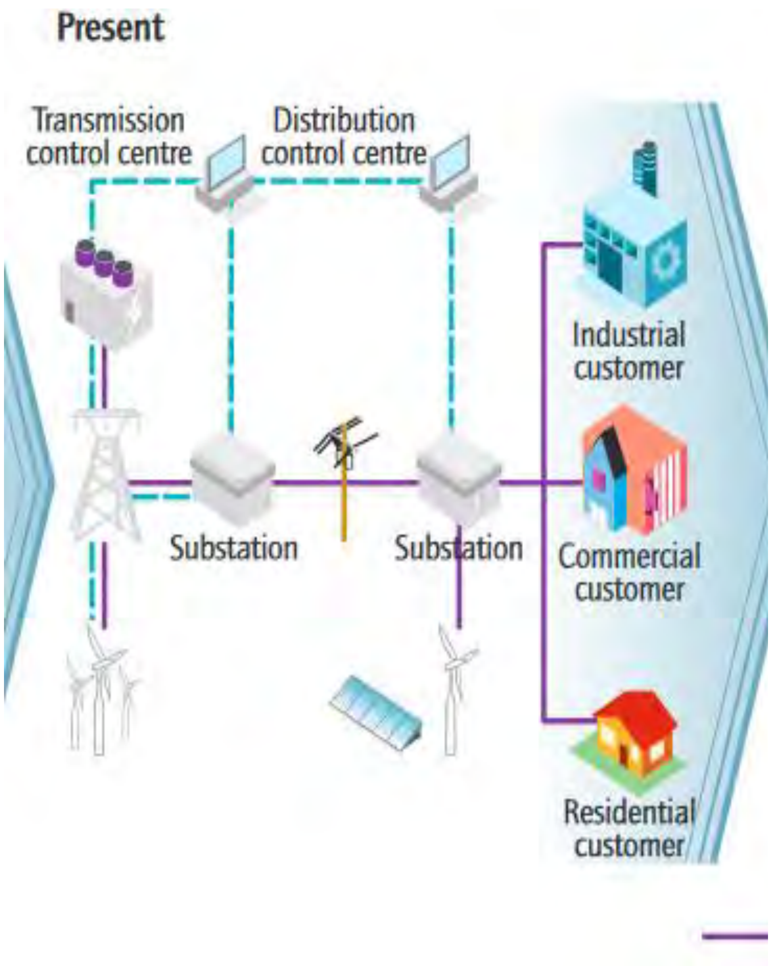
New material needs by 2030	
Li and Sulphur, improved conductive polysulphides	- Na-Ion materials - new redox flow systems materials - molten metal/salt systems - introduction of Al or Mg in metal-air, metal-sulphide or ion based systems
Development of new solid electrolytes (non-polymer)	
Development of correctly rechargeable Zn or Li-anodes, electrolytes and air cathodes	

[Source: European Energy Storage Technology Development Roadmap Towards 2030 - Roadmap 2013]

BUT
Success will depends on several factors (not only on energy und power density)

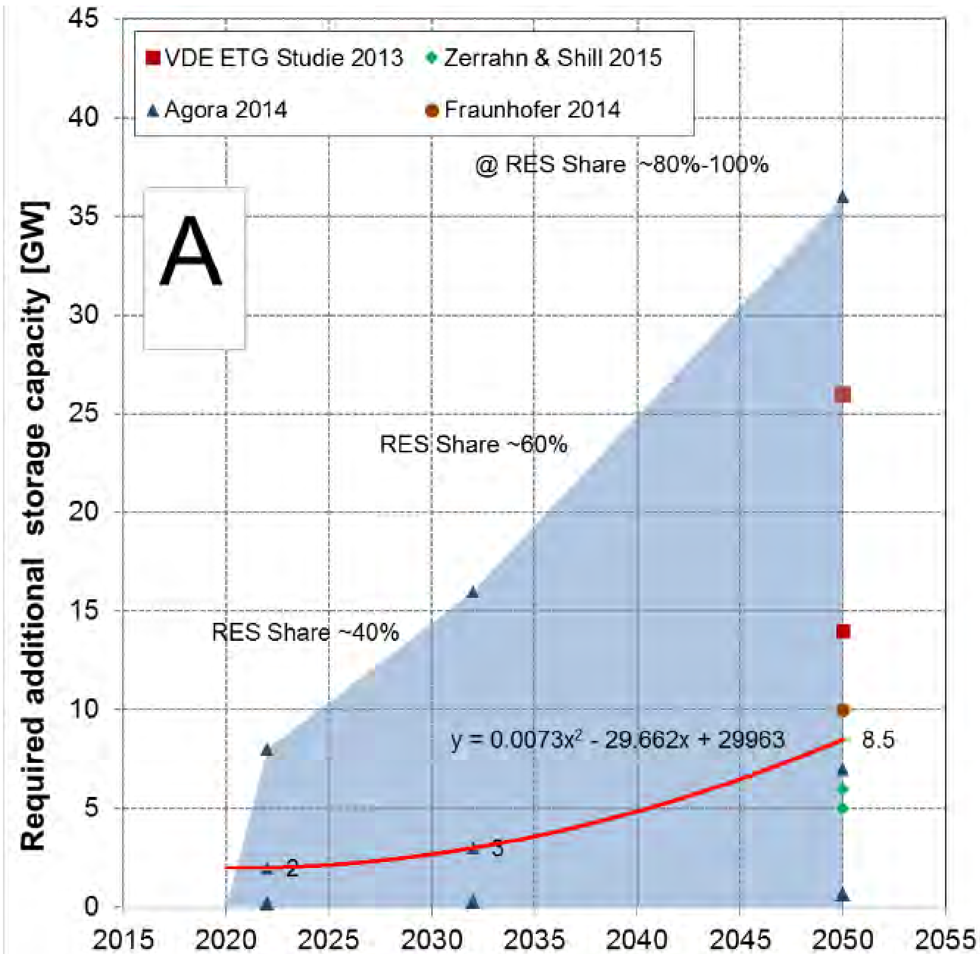
- Costs (production costs, LCC) – Resource availability
- Cycle lifetime
- Calendric lifetime
- Robustness
- Resistance (energy losses)/ Self Discharge
- Safety
- Application specific needs
- …
- Recyclability

Energy Transition
Need for Energy Storage



[IEA, “Technology roadmap: Smart Grids, 2011]

Potential required storage capacity, short-mid duration (4<x<5 h per day) until 2050



Quelle: Baumann 2018

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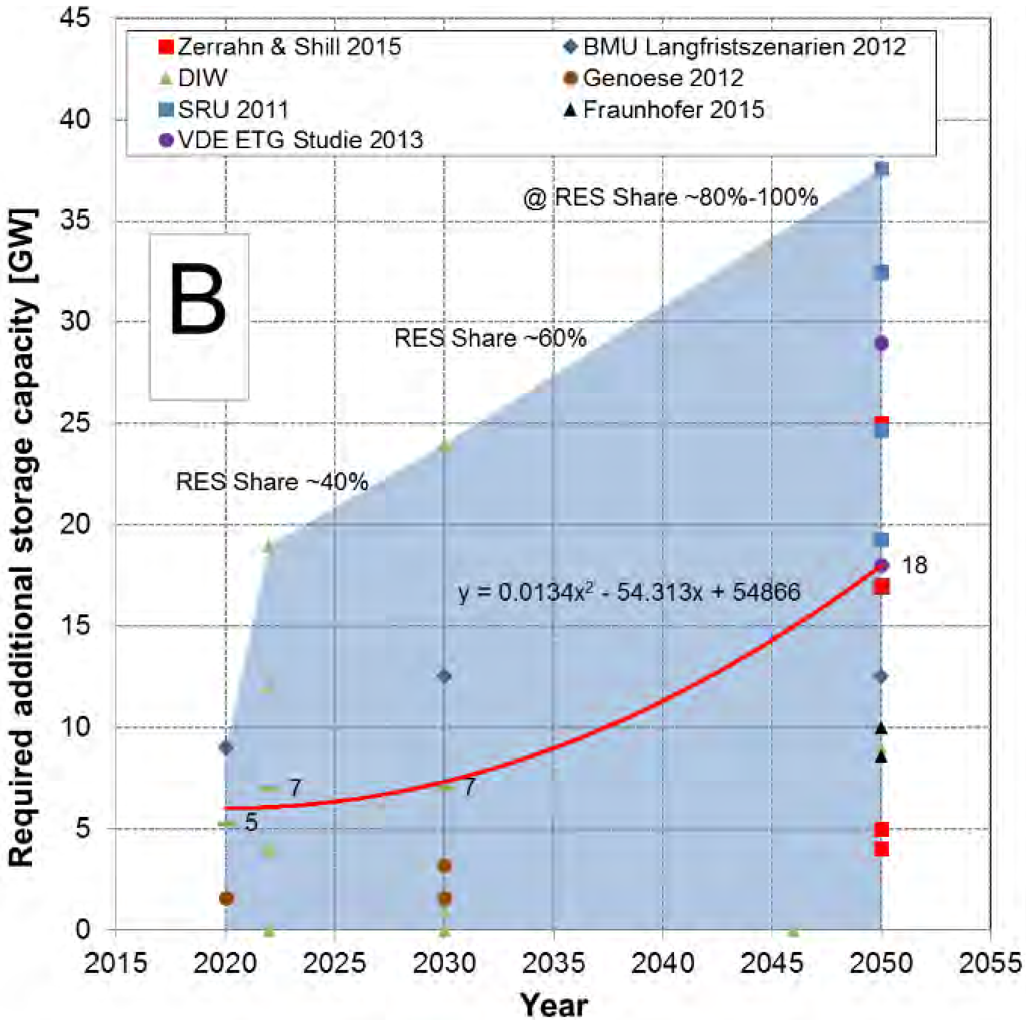
Potential required storage capacity, mid duration (8<x<10 h per day) until 2050



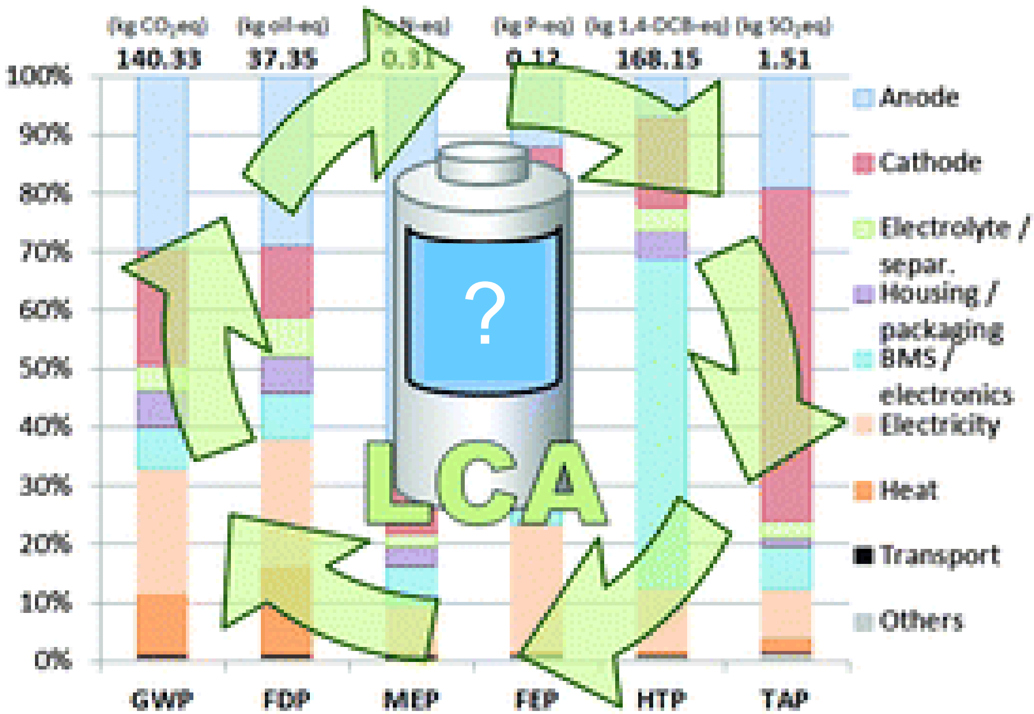
Quelle: Baumann 2018

But which Flex Option for the Grid?
Only batteries?

- Extension of transmission grid
- Sector coupling (Heat, Electricity, Mobility)
- Load management
- …

- ❑ (Synthetic fuels (Power to gas (H2, etc.) – Fuel cells))
- ❑ (CAES storage)
- ❑ (Pumped hydro storage)
- ❑ (Flywheels), …

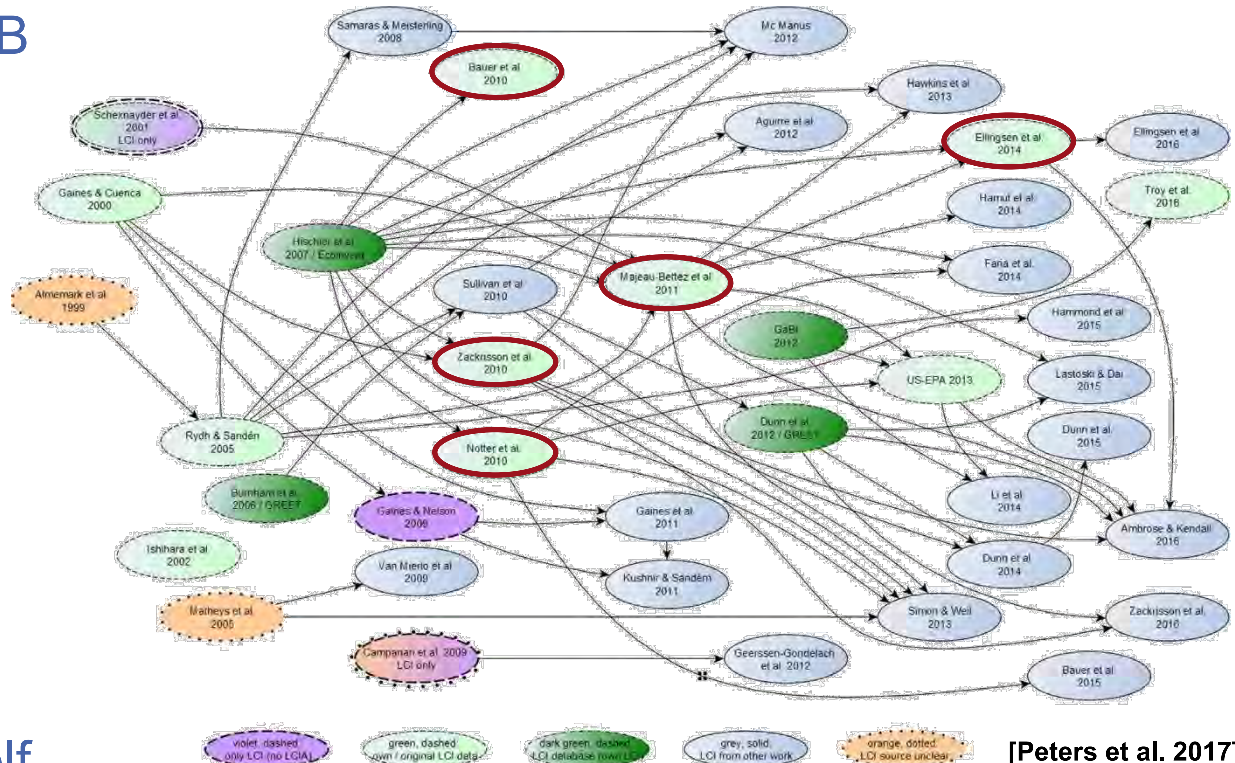
LCA for Energy storage systems



Before analyze Post Li- System
Understand the present Li-Systems

- Many available studies, but few original LCI datasources, often quite old

- Covering 5 different LIB chemistries:
  - LFP-LTO
  - LFP-C
  - LMO-C
  - NCM-C
  - NCA-C



[Peters et al. 2017]

- Assumptions in many case more important for LCA results, than battery chemistries itself

- Social LCA not found in literature
  Own investigation: Zimmermann et al. 2015-SETAC

Before analyze Post Li- System
Understand the present Li-Systems

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Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The environmental impact of Li-Ion batteries and the role of key parameters – A review

CrossMark

Jens F. Peters [a,*], Manuel Baumann [b,c], Benedikt Zimmermann [b], Jessica Braun [b], Marcel Weil [a,b]

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Present Batteries for stationary application Four application cases:

- **ETS**

Electric time shift (ETS)/ , “Arbitrage”
Energy/Power = 4

- **PVSC**

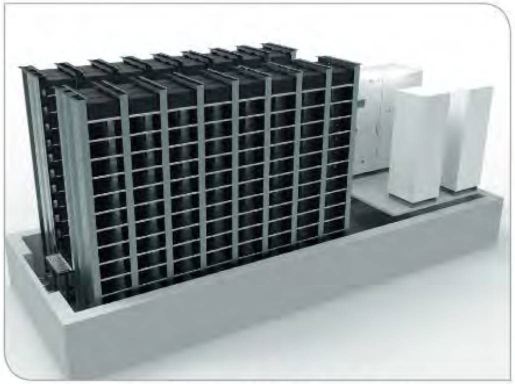
Increase of photovoltaics self-consumption
Energy/Power = 3,2

- **PR**

Primary regulation
Energy/Power = 1

- **RS**

Renewables support
Energy/Power = 10



Innenansicht des Großspeichers (Bild: build_up design)

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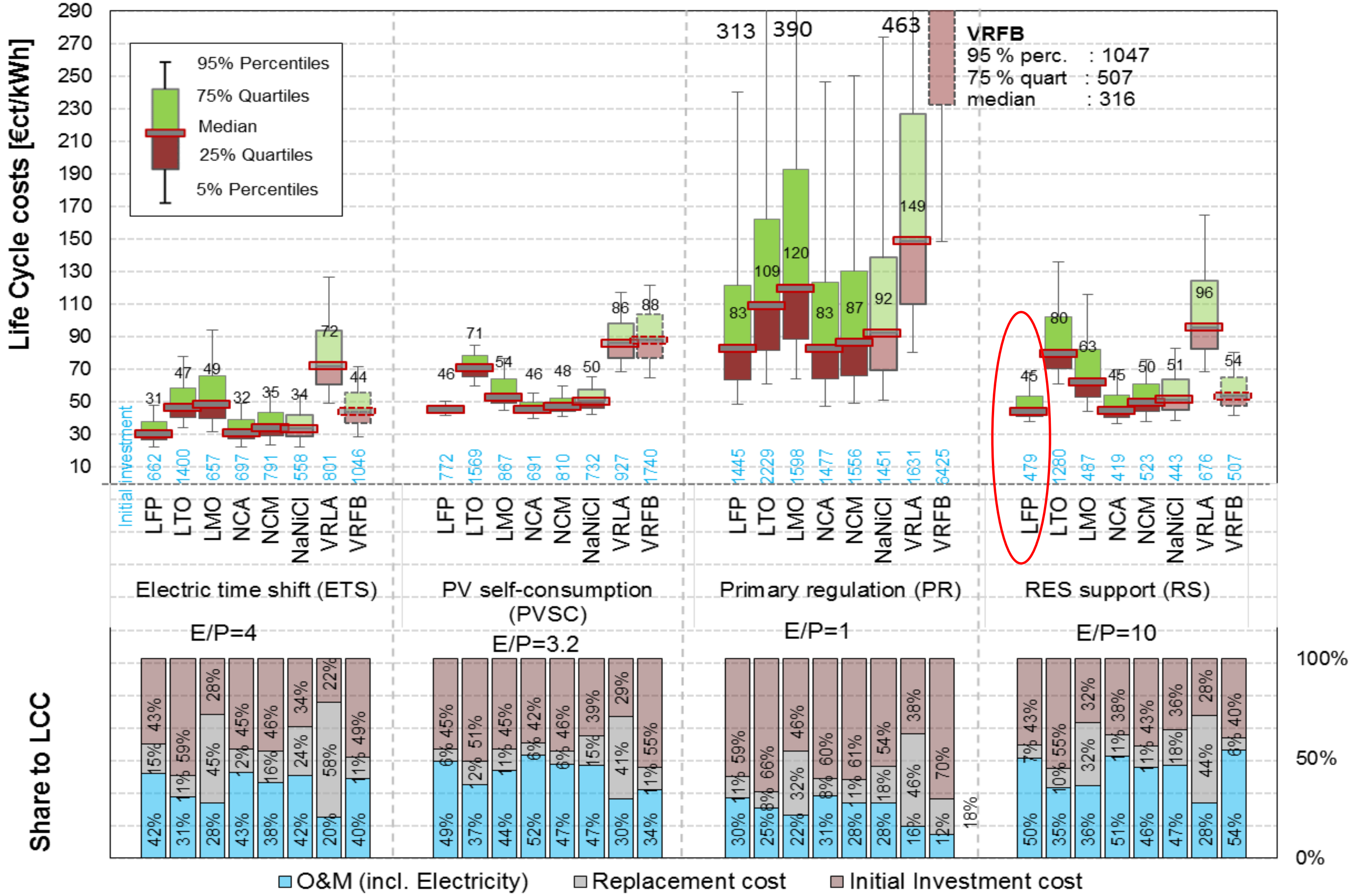
Considered batteries

- **LFP** lithium-iron-phosphate with graphite anode (LIB chemistry)
- **LTO** lithium-iron-phosphate with lithium-titanate anode (LIB chemistry)
- **NCM** lithium-nickel-cobalt-manganese-oxide with graphite anode (LIB chemistry)
- **NCA** lithium-nickel-cobalt-aluminum-oxide with graphite anode (LIB)
- **LMO** lithium-manganese-oxide with graphite anode (LIB chemistry)
- **NaNiCl** sodium-nickel-chloride battery
- **VRFB** vanadium redox flow battery
- **VRLA** valve regulated lead acid

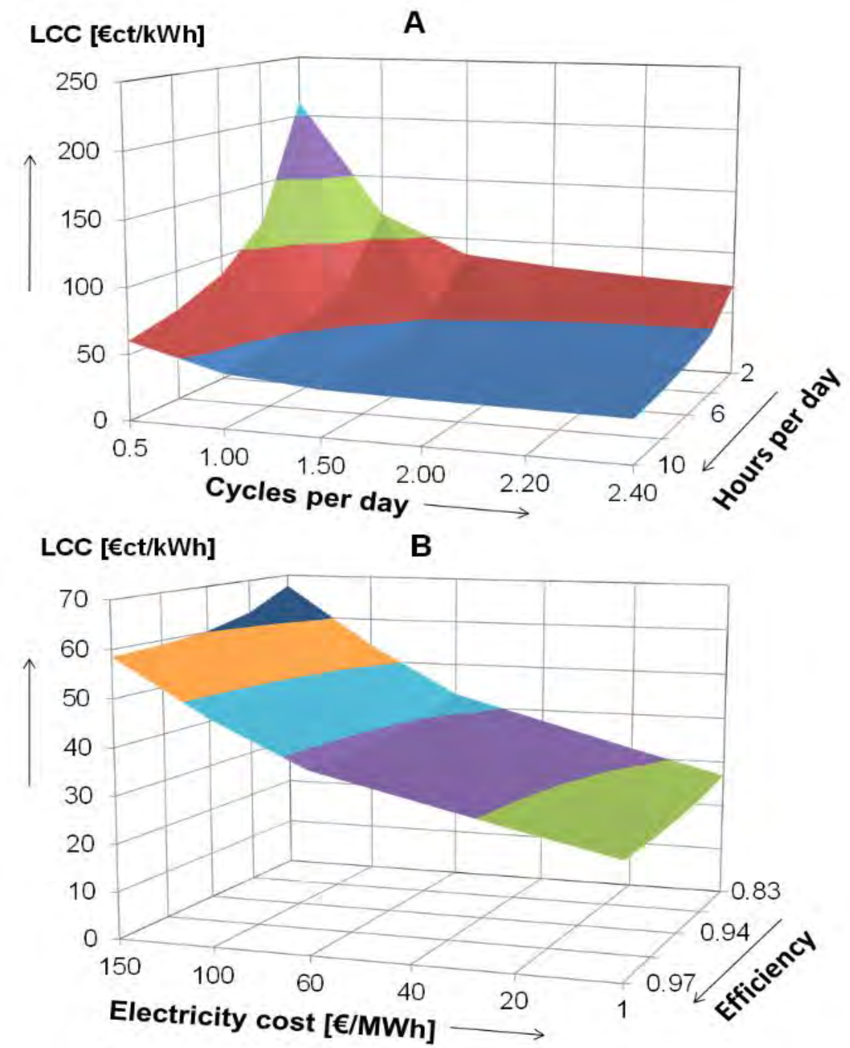
Costs

LCC for batteries – stationary application



[Baumann et al. 2017]

Sensitivity Analysis
Costs

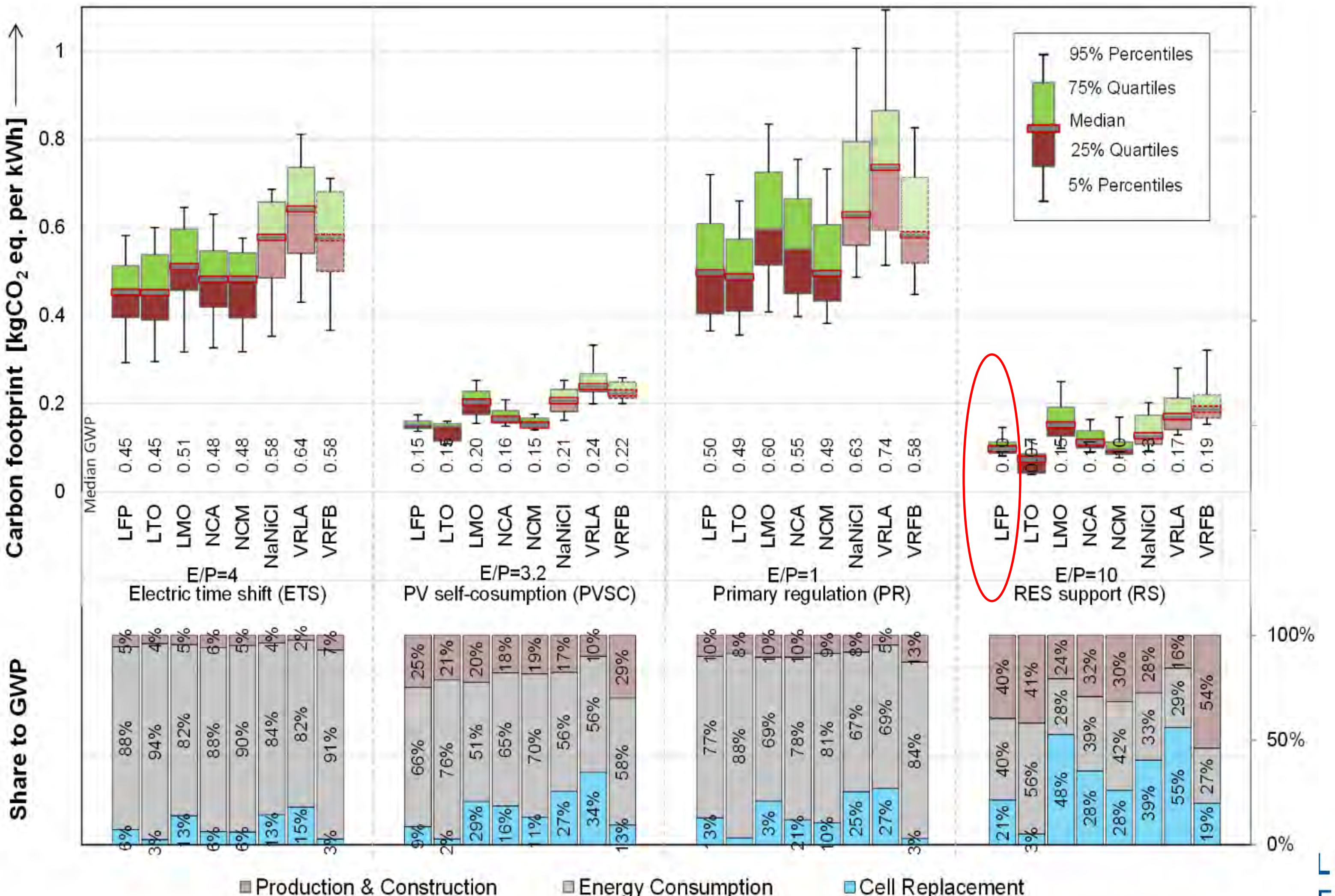


A)
operation conditions including number of cycles and charging time per cycle

B)
Influence of efficiency and purchased electricity.

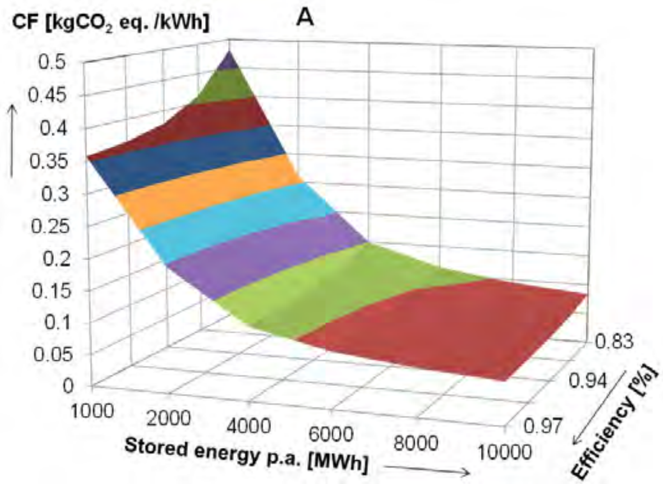
GWP

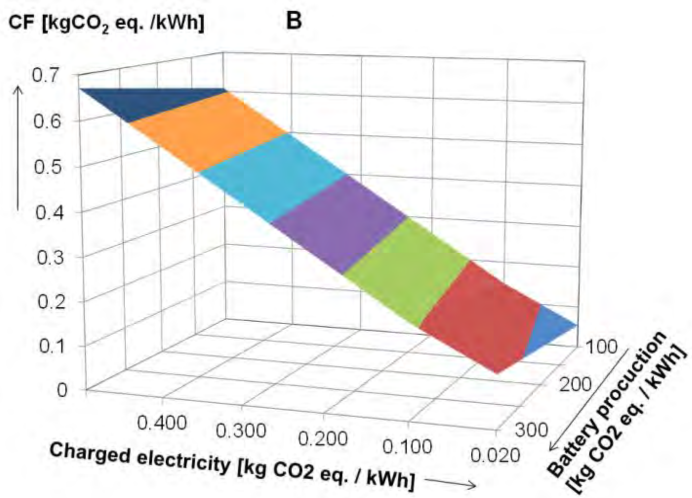
CO2-Footprint (GWP)



[Baumann et al. 2017]

Sensitivity analysis
CO2-Footprint





A)
Variation of efficiency and total stored energy per year

B)
battery production vs. charged electricity

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Energy Technology

Generation, Conversion, Storage, Distribution

Full Paper

CO_2 Footprint and Life-Cycle Costs of Electrochemical Energy Storage for Stationary Grid Applications

M. Baumann, Dr. J. F. Peters, Dr. Ing. M. Weil, Prof. Dr. A. Grunwald

First published: 21 February 2017 Full publication history

DOI: 10.1002/ente.201600622 View/save citation

Early View

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Abstract

Batteries are considered as one of the key flexibility options for future energy storage systems. However, their production is cost- and greenhouse-gas intensive and efforts are made to decrease their price and carbon footprint. We combine life-cycle assessment, Monte-Carlo simulation, and size optimization to determine life-cycle costs and carbon emissions of different battery technologies in stationary applications, which are then compared by calculating a single score. Cycle life is determined as a key factor for cost and CO_2 emissions. This is not only due to the required battery replacements but also due to oversizing needed for battery types with low cycle lives to reduce degradation effects. Most Li-ion but also the NaNiCl batteries show a good performance in all assessed applications whereas lead-acid batteries fall behind due to low cycle life and low internal efficiency. For redox-flow batteries, a high dependence on the desired

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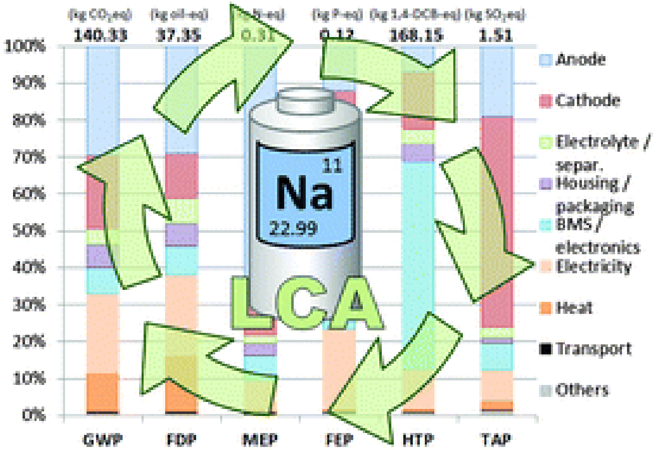
Emergent Battery Technologies for stationary applications

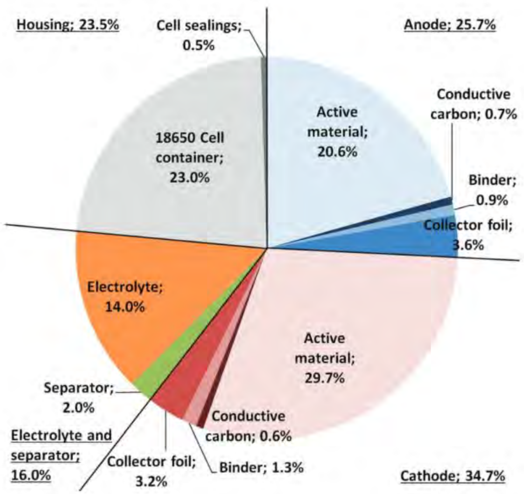


[Peters et al. 2016]

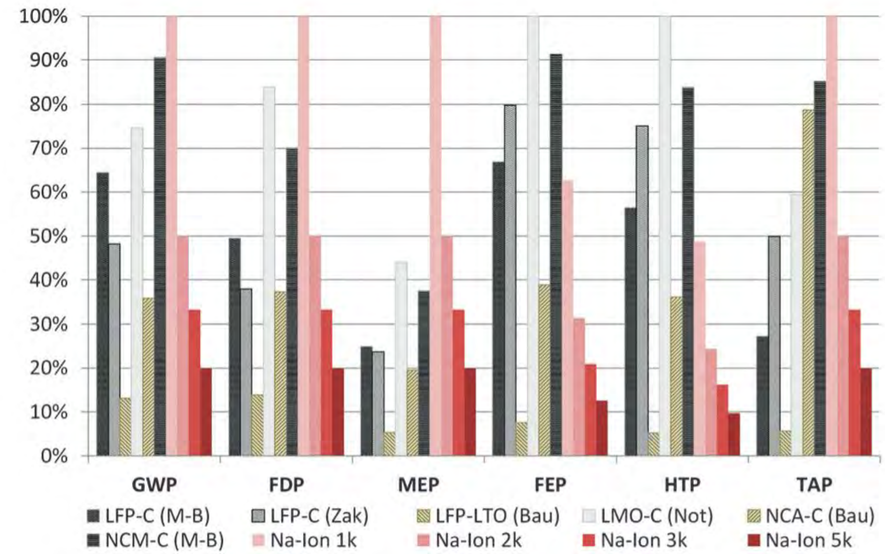
Advantages of Sodium batteries:

- ❖ Based on cheap and good available elements and raw materials
- ❖ Technical performance seems to be very promising in this early stage
- ❖ Can be produced (on industrial level) very similar to Li-Ion batteries
- ❖ Hard carbons can be produced from organic waste

LCA Sodium Battery



weight%, Na-battery



Energy & Environmental Science

ROYAL SOCIETY OF CHEMISTRY

PAPER

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Cite this: *Energy Environ. Sci.*, 2016, 9, 1744

Life cycle assessment of sodium-ion batteries†

Jens Peters,*[ab] Daniel Buchholz,[ab] Stefano Passerini*[ab] and Marcel Weil[abc]

Sodium-ion batteries are emerging as potential alternatives to lithium-ion batteries. This study presents a prospective life cycle assessment for the production of a sodium-ion battery with a layered transition metal oxide as a positive electrode material and hard carbon as a negative electrode material on the battery component level. The complete and transparent inventory data are disclosed, which can easily be used as a basis for future environmental assessments. Na-ion batteries are found to be promising under environmental aspects, showing, per kWh of storage capacity, environmental impacts at the lower end of the range published for current Li-ion batteries. Still significant improvement potential is given, especially by reducing the environmental impacts associated with the hard carbon production for the anode and by reducing the nickel content in the cathode active material. For the hard carbons, the use of organic waste can be considered to be promising in this regard. Nevertheless, when looking at the energy storage capacity over lifetime, achieving a high cycle life and good charge–discharge efficiency is fundamental. This represents the main challenge especially when competing with LFP–LTO type Li-Ion batteries, which already show extraordinarily long lifetimes.

Received 1st March 2016, Accepted 21st March 2016

DOI: 10.1039/c6ee00640j

www.rsc.org/ees

GWP = global warming potential,
FDP = fossil depletion potential,
MEP = marine eutrophication potential
FEP = freshwater eutrophication potential
HTP = human toxicity potential
TAP = terrestrial acidification potential

LFP–C: 2960 cycles; **LFP–LTO**: **13 850** cycles;
LMO–C: 1070 cycles; NCA–C: 2200 cycles
NCM–C: 1650 cycles

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Costs Sodium Batteries

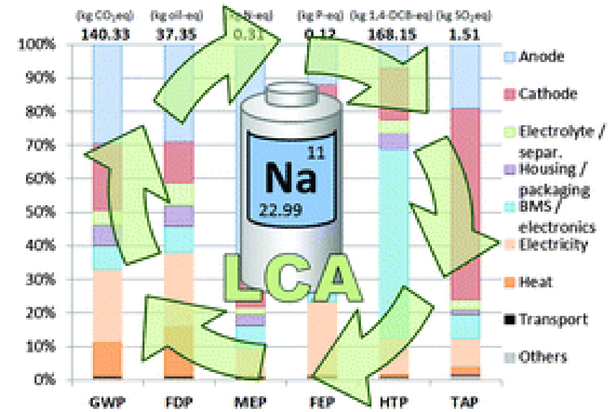
❖ Use of BatPaC, production costs

  ➢ Black box

Major results:

❖ Cost saving are less as very often discussed

❖ Major saving due to exchange of Cu-Foil by Al-Foil as current collector



[Peters et al. 2016]

nature REVIEWS MATERIALS

Altmetric: 136 More detail »

Perspective

A cost and resource analysis of sodium-ion batteries

Christoph Vaalma, Daniel Buchholz, Marcel Weil & Stefano Passerini

Nature Reviews Materials **3**, Published: 13 March 2018

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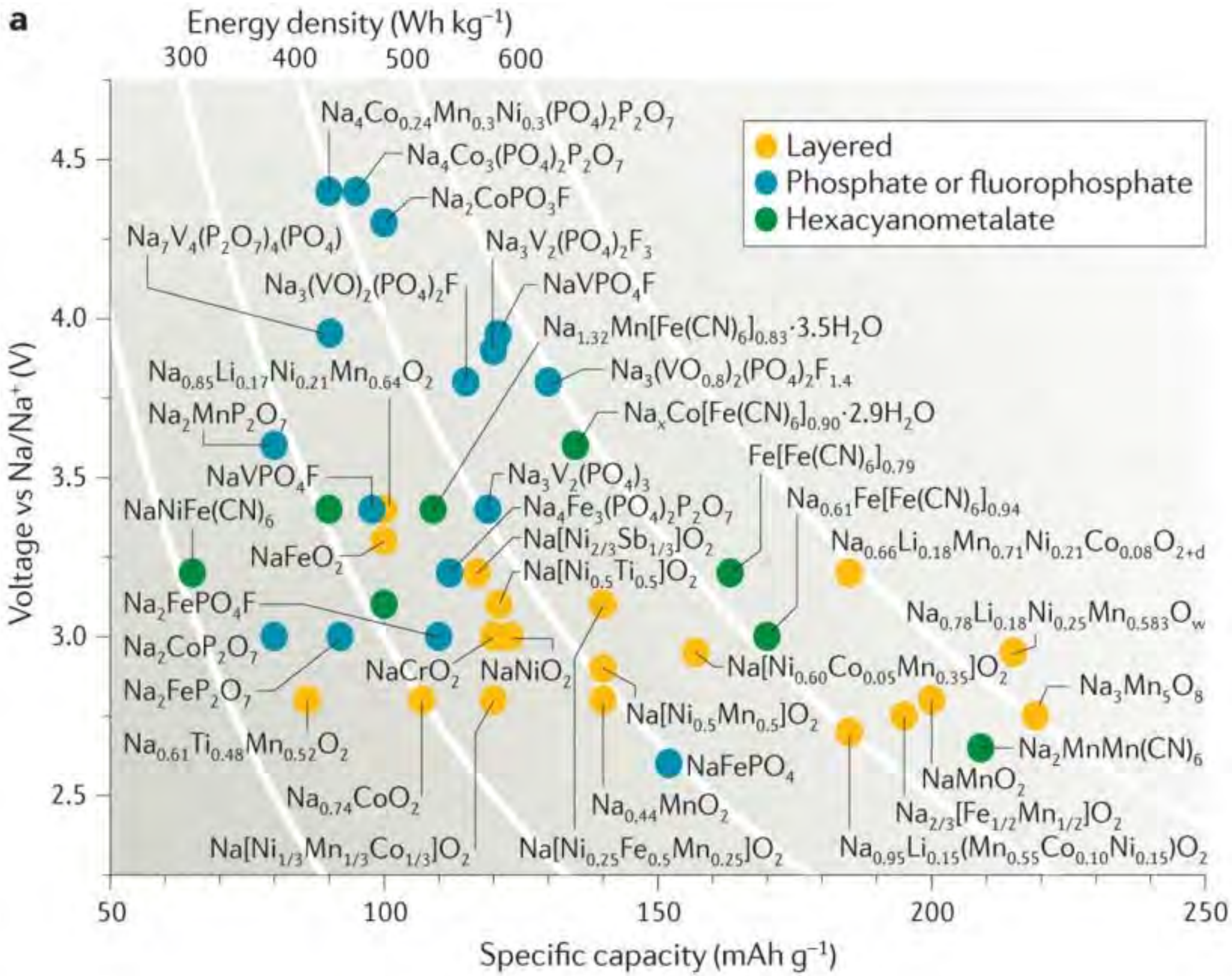
Sodium-ion battery electrode materials



Operation voltages versus specific capacities of sodium-ion battery electrode materials

Source: Choi, J. W. & Aurbach, D. (2016) Promise and reality of post-lithium-ion batteries with high energy densities. *Nat. Rev. Mater.* doi:10.1038/natrevmats.2016.13

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Stationary "Saltwater Battery"
Aqueous hybrid ion battery (AHIB)

AQUION ENERGY

Picture: C2C Centre

Advantages

- *Low investment costs (~ Li-Ion)*
- *Very high cycle life*
- Minimal degradation
- Little thermal management
- Environmental friendly materials
- Non-Toxic
- Neither flammable nor explosive
- …

Picture: Aquion Energy.

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“Saltwater Battery”
Aqueous hybrid ion battery (AHIB)

AQUION ENERGY

Picture: C2C Centre

AQUION

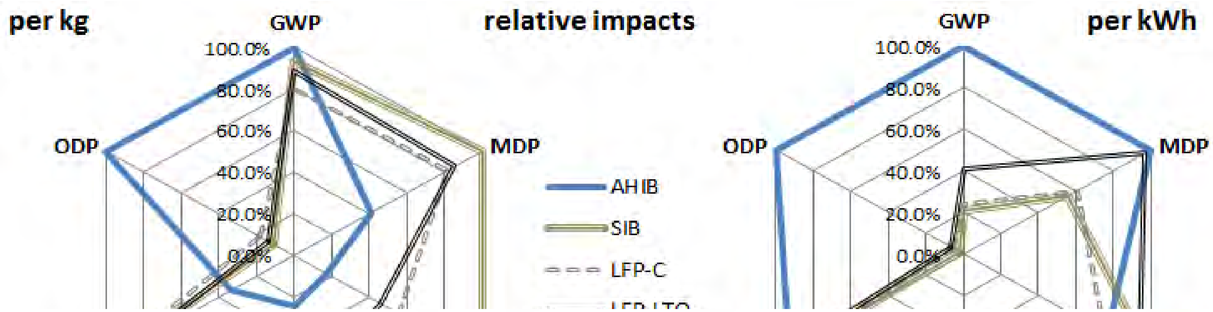
- *Founded by* Dr. Jay Whitacre
- *Won MIT Price*
- *Investor: Bill Gates, …*
- *Cradle* to *Cradle* Certified™

Picture: Aquion Energy.

Unfortunately

- *Bankrupt March 2017*
- *Sold to “China”*
- *Company deconstructed*
- *Production in China?*

LCA



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Journal of Power Sources

Volume 364, 1 October 2017, Pages 258-265

Aqueous hybrid ion batteries – An environmentally friendly alternative for stationary energy storage?

Jens F. Peters [a], Marcel Weil [a, b]

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https://doi.org/10.1016/j.jpowsour.2017.08.041

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GWP MDP AP EP HTP ODP

AHIB SIB LFP-C LFP-LTO

Relative impacts associated with providing 1 kWh of stored electricity from a residential PV system over the lifetime of each battery

Stationary Applications
Vanadium Redox Flow Battery

Example: VRF-Battery Pfinztal

- 20 MWh capacity
- 2MW power
- 650.000 L electrolyte

ICT Fraunhofer, Pfinztal

Pictures: BNN, KA-News, SWR

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Stationary Applications
Vanadium Redox Flow Battery

System Analysis perspective:

- Several techno-economic assessments of VRFB exists
- Only one simplified, outdated LCA available
  - C. J. Rydh, *J. Power Sources*, 1999.
- Many publications which consider environmental issues refer to this outdated LCA
- Urged need for updated, reliable LCA for VRFB
  - Paper submitted to Energy & Environmental Science

Environmental assessment of vanadium redox flow batteries

Christine Minke[1], Jens F. Peters[2], Manuel Baumann[3,4], Marcel Weil[2,3]
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[3]Karlsruhe Institute of Technology – Institute for Technology Assessment and Systems Analysis, Germany
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The relevance of the end-of-life stage for the environmental impact of batteries

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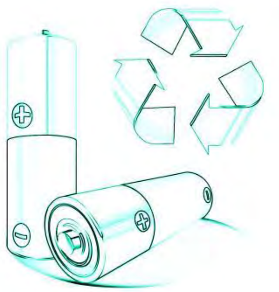
Announcement

Workshop und Expertenforum

"Recycling aktueller und
zukünftiger Batteriespeichertechnologien„
6. Juni 2018
ITAS/HIU, Karlsruhe
https://stage.itas.kit.edu/veranstaltungen.php



Open PhD Position

Life Cycle Analysis of high temperature superconductors for future grid applications
ITAS/ITEP Karlsruhe

FastGrid
Picture: oxolutia

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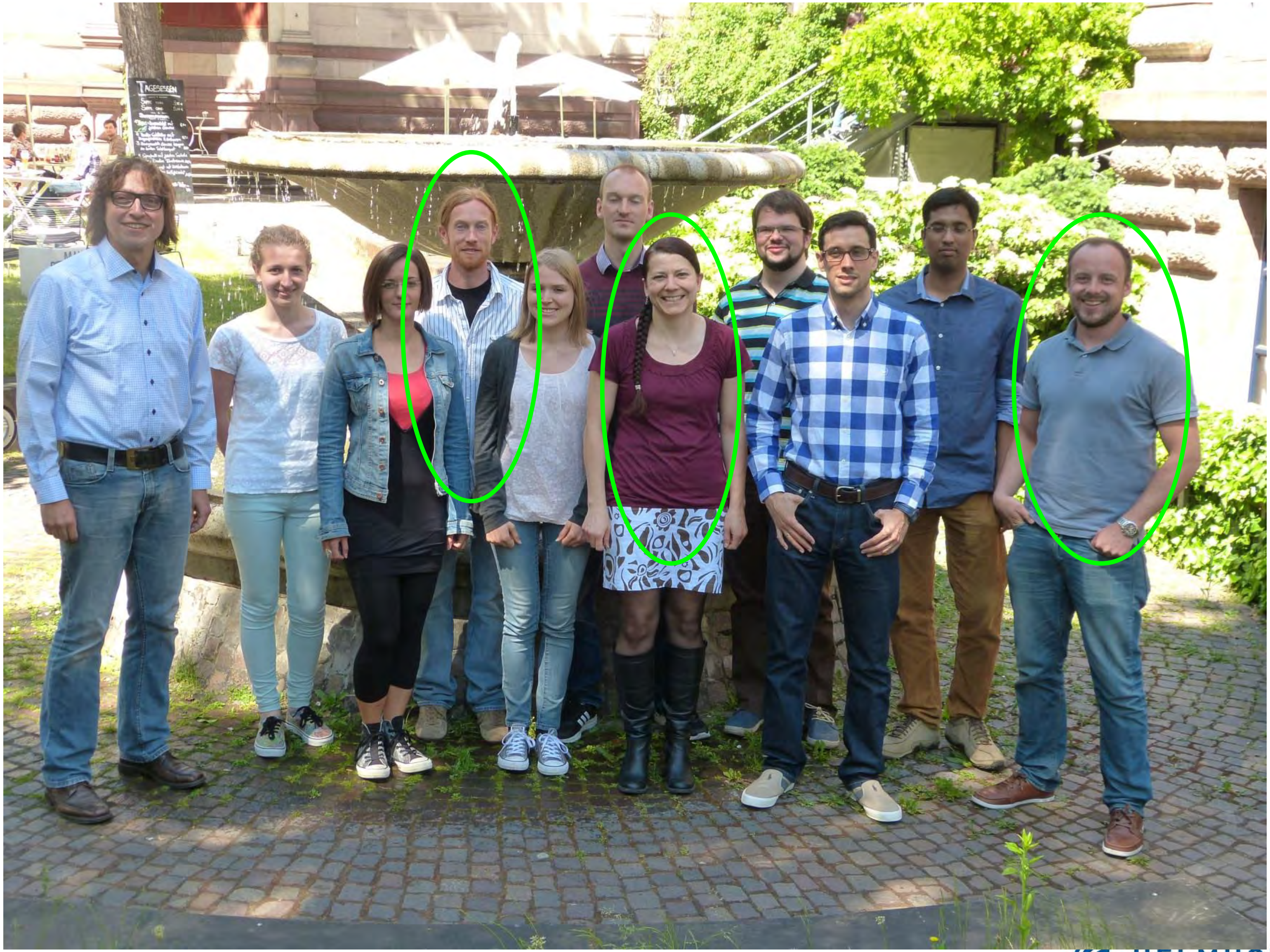

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Thank You

Helmholtz Institute Ulm for
Electrochemical Energy Storage
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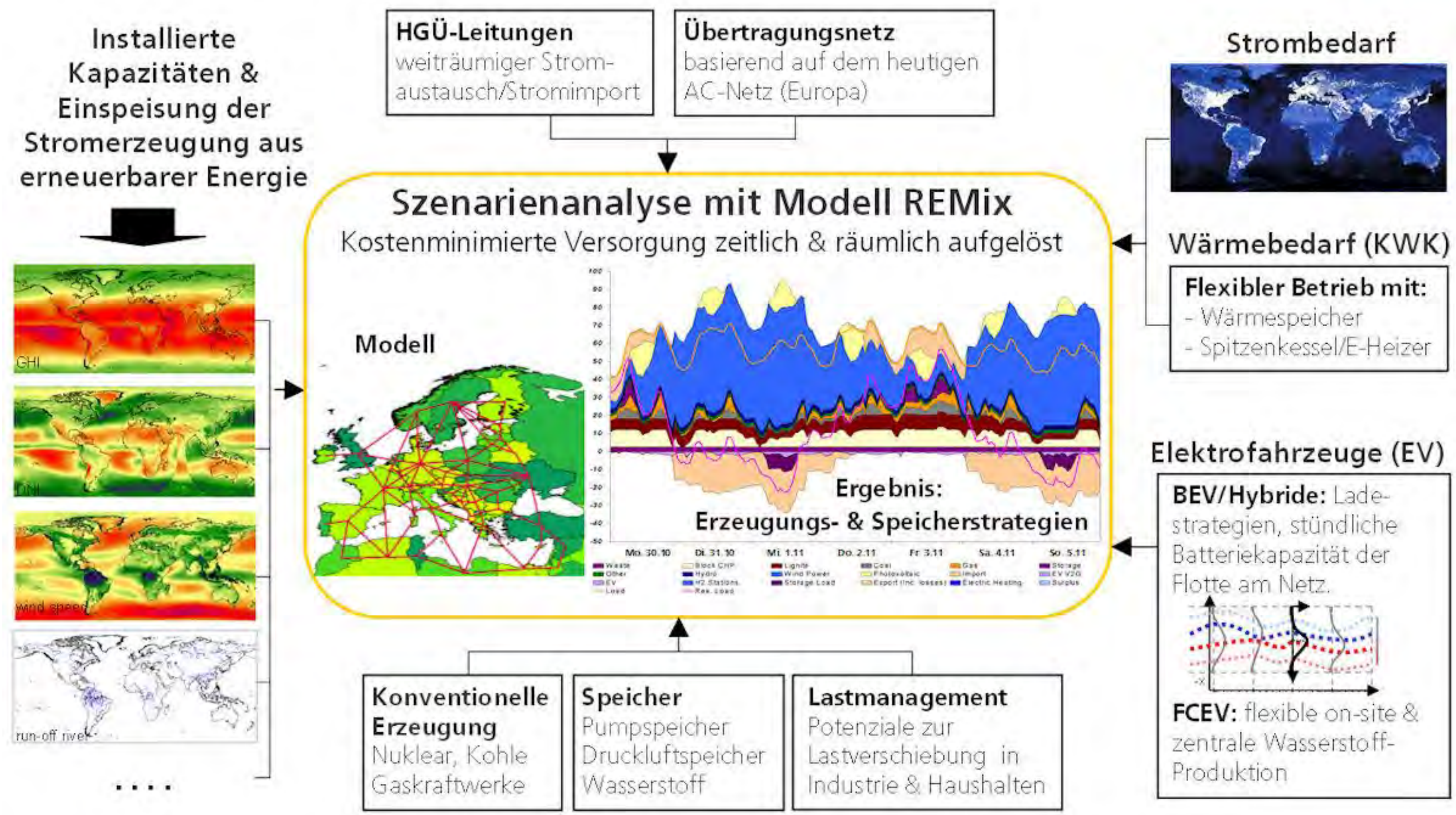
ReMix-Model (DLR) – ES 2050



Picture: DLR - Forschung-Energiespeicher

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Conference paper (Scopus)

Environmental Impacts of different Battery Technologies in Renewable Hybrid Micro-Grids

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Elizabeth Wanner
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***Abstract* – Battery storage is considered as crucial for the safe operation and design of hybrid micro-grid systems (HMGS) by balancing load and generation from renewable energy sources. However, several battery technologies are available for this purpose, with different greenhouse gas emissions associated with their production. This paper applies a canonical differential evolutionary particle swarm algorithm for optimizing HMGS design and operation. Optimization goals are minimization of electricity costs and loss of power supply probability and maximization of renewable shares. The global warming potential of the obtained HMGS supported by different battery technologies is then determined via life cycle assessment. Results indicate that all the considered battery types lead to environmental benefits when compared with a HMGS without storage. Lithium iron phosphate and sodium nickel chloride batteries show favorable results whereas lead acid and lithium manganese oxide batteries are ranked last.**

users. HMGS can be described as clusters of small generators, loads and battery energy storage systems connected through a local electricity network, controlled by a power management system that optimizes power flows [1]. A major challenge of such grids is the fluctuating generation behavior of decentralized sources as photovoltaics and wind turbines which correlate only poorly with loads. Battery storage technologies allow matching intermittent generation with local demand and are thus seen as a crucial factor for a safe and reliable HMGS operation. However, production, use and disposal of battery storage systems are also associated with potentially negative effects on the environment. Especially the production of the batteries is greenhouse gas intensive, why continuous efforts are being made to reduce their environmental impact in the future [2]. In spite of that, only a very limited number of studies exists that try to quantify the environmental impact of batteries in stationary applications [3]–[7]. Even less studies are available that tackle the effect of

Poster

23rd SETAC Europe LCA Case Studies Symposium
Consequential LCA for Decision Support
27–28 November 2017 | Barcelona, Spain
Organised in cooperation with the International Life Cycle Academy
SETAC

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ITAS

Dynamic LCA of stationary battery systems in renewable based decentralized grids

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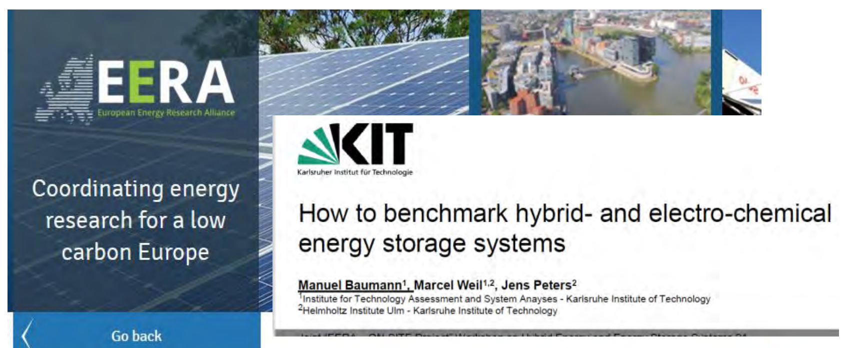
2) Helmholtz Institute Ulm for electrochemical energy storage (HIU/KIT)
3) Faculdade de Ciências e Tecnologia (FCT), Universidade Nova de Lisboa (UNL)
4) Centro Federal de Educação Tecnológica de Minas Gerais (CEFET-MG)

INTRODUCTION
- Integration of Renewables Energy Systems (photovoltaics and wind turbines) within decentralized grid systems (DG)
- Batteries one of the key technologies to match load and generation for this purpose
- Production associated with environmental impacts → decrease price and env. footprint
- **Aim of work:** Decision aid for choosing most suitable battery type in environmental terms

METHODOLOGY
- A Micro-grid optimization model + LCA (use case small village in south Germany)

System boundary

Eingeladener Vortrag



"EERA-ONSITE Project" Workshop on Hybrid Energy and Energy Storage Systems, 21-22 Sept 2017, Rome

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