Rechargeable aqueous Li-ion batteries for stationary application

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Astana 2017

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Agenda

- Introduction
- Safe and ecological batteries for renewable energy
- Conclusions

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Kazakhstan

Population 16,1 mln (2014). Capital: Astana (since

- **Nazarbayev University (founded in 2011)**
- **National Laboratory Astana**
- **Institute of Batteries** (Startup company, 2013)

Prof. Z. Bakenov

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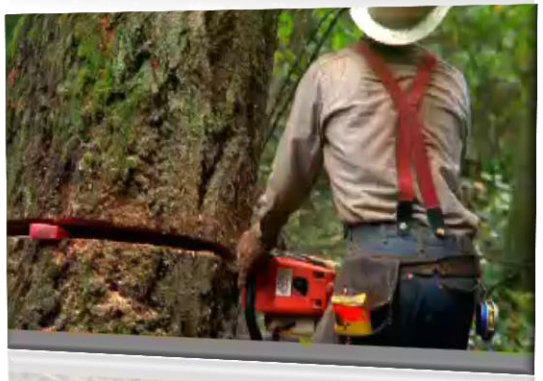
Astana – capital of Kazakhstan

Economic development and Energy needs



Video source:VidLib

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Environmental Crisis

Video source:VidLib

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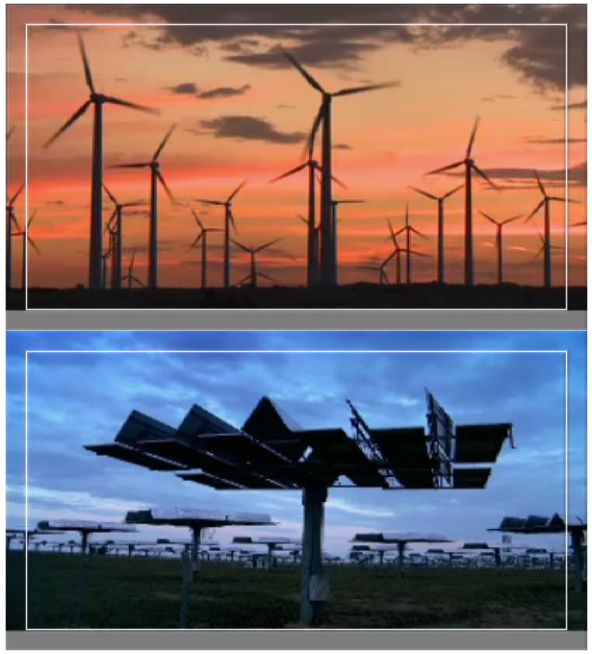
Renewable energy sources



Video source:VidLib

Expo2017: Future Energy, Astana

Clean, Affordable, Domestic, Effectively infinite

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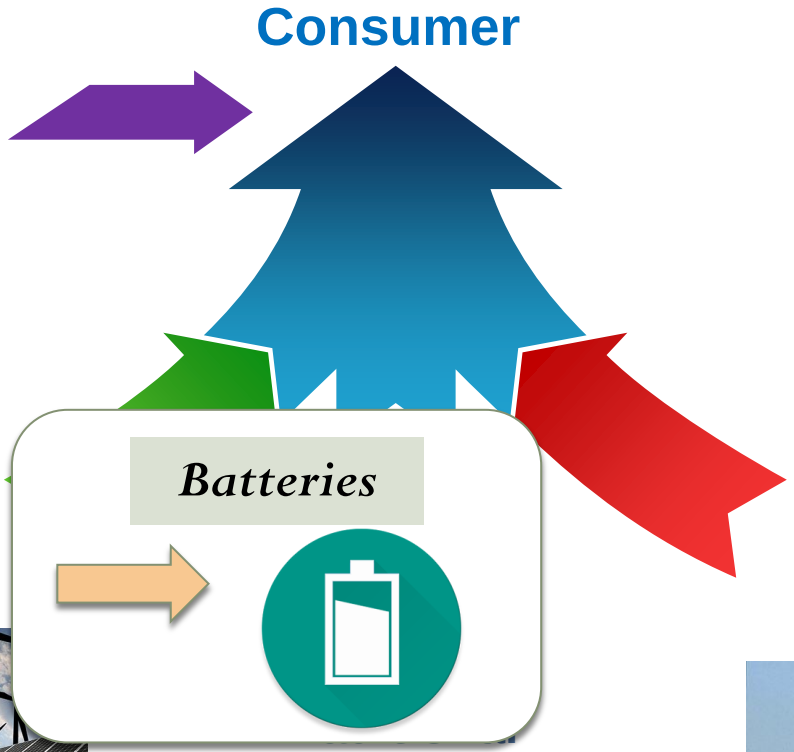
Development of renewable energy technologies

Renewable energy sources improve self-sufficiency rate of energy and reduce global environmental challenges and warming.



Intermittent and variable energy resources

Market potential for Energy Storage

Piper Jaffray, World Wind Energy Association, EPIA

Wind and Solar in Kazakhstan

- **Wind**
  - Djungar Gates (East side of Kazakhstan) - 525W/m^2
  - Chylyk Corridor(South side of Kazakhstan) - 240W/m^2
- **Solar**
  - Kazakhstan's estimated solar energy potential is 2.5 billion kilowatts a year a result of its 3000 hours of sunlight a year.

http://kzgreenenergy.com

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Research Projects

- Innovation/industrialization Program of NU (administered by the Commercialization Office of NURIS)
  - Ecologically Friendly Batteries for Grid Connection of Renewable Sources and Electric Vehicles
- Subproject of Technology Commercialization Program of World Bank and Government of Kazakhstan
  - Development of innovative lithium metal-free lithium-ion sulfur battery for renewable energy, electric transport and electronics
- Subproject of Technology Commercialization Program of World Bank and Government of Kazakhstan
  - Proof of concept on flow-assist-free Zn/NiOOH battery
- Marie Curie Industry-Academia Partnerships and Pathways (IAPP) Call: FP7-PEOPLE-2012-IAPP
  - Advanced technologies for clean-up of water and soils from xenobiotics

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Research Projects (cont)

- National Atomic Company KazAtomProm
  - Synthesis of High Energy Density Cathode Materials
- Nazarbayev University funding
  - Development of Innovative Rechargeable Aqueous Lithium-Ion Battery for Large Scale Energy Storage
  - Nanotechnique for the degradation of antibiotics by means of physical agents
- The National Plan for Science, Technology and Innovation, Saudi Arabia
  - Synthesis of Carbon Microspheres and Hydrochar from Date Palm (Phoenix dactylifera) Biomass Wastes and Its Application for Wastewater Treatment
- The Ministry of Education and Science of Kazakhstan
  - Six projects (Project on 3D Aqueous battery)

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Ministry of Education and Science

- Development of innovative non-flammable, low cost, and highly durable rechargeable battery (Dr. A. Molkenova, Dr. Z. Bakenov)
- Development and optimization of preparation of graphene using liquid metal catalyst (Dr. R. Tussupbayev, Dr. Z. Bakenov)
- High energy density polymer lithium-sulfur battery for renewable energy, electric transport and electronics (Dr. A. Mentbayeva, Dr. Y. Zhang)
- High Capacity and Rate Capability Silicon Based Anode Materials with Maximum Safety (Dr. T.O. Ely, Dr. Z. Bakenov)
- Development of a novel quartz (SiO_2) based composite anode material for Li-ion batteries (Dr. R.M. Babaa, Dr. Y. Zhang, Dr. Z. Bakenov)
- Development of economically feasible three-dimensional lithium/sulfur battery (Dr. Z. Bakenov, Dr. A. Nurpeissova).

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Research directions in our group

- **Aqueous RALB**

Lithium-Ion Batteries (LIBs)

- LIBs leading the market for portable electronics and electric transport.

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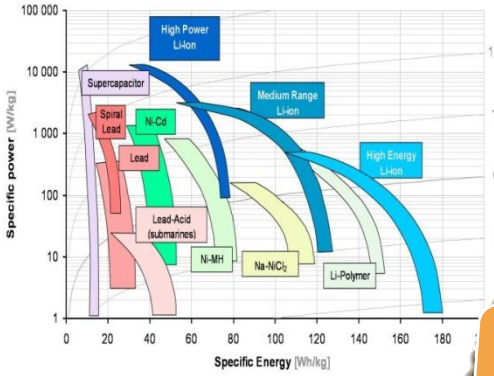
Lithium-Ion Batteries

Advantages *Disadvantages*



High energy density

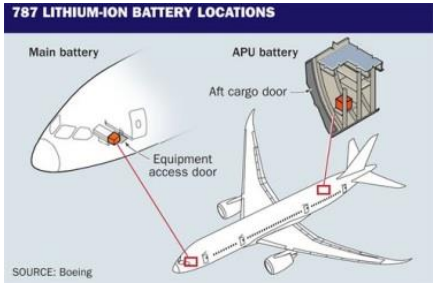
High operation potential

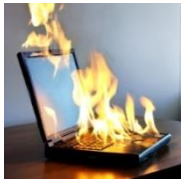
High cyclability

Toxic

High cost

Flamability





- V

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Ideal battery for large scale applications

- Organic electrolyte replaced by non-flammable, air and moisture stable alternative
- Low-toxicity cathodes …

Solution?

- **Aqueous electrolyte**
- **$LiFePO_4$ cathode**

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Rechargeable aqueous lithium-ion battery (RALB)

- **Absolutely safe**
- Enhanced energy density
- Matured cathode technologies - “borrowed technologies”
- Low cost and abundant materials supply
- Simple manufacturing (in open air conditions)
- Ecologically friendly (no lead or acids)
- Addressed safety issues (nonflammable mild acidic water based electrolyte)

Applications: Large scale energy storages, Electrical Vehicle

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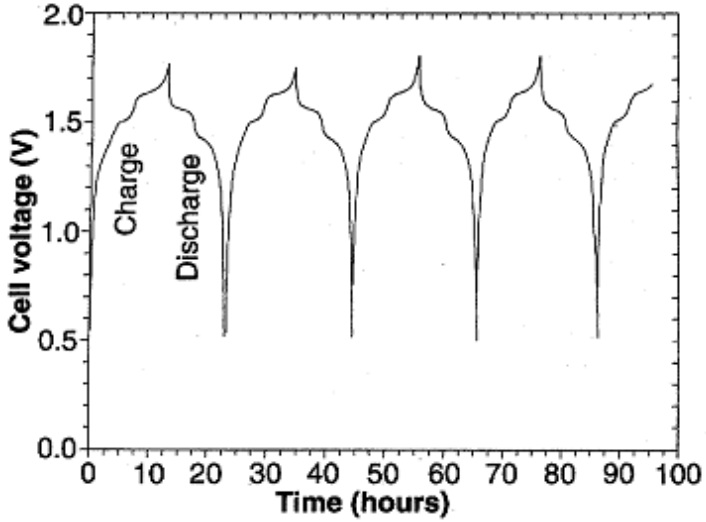
Rechargeable Aqueous Lithium-Ion Batteries (RALBs)

- The battery should be one combining the stability and energy density of LIBs with the advantages of aqueous batteries, which could remarkably reduce the cost of the energy storage.



W. Li, J.R. Dahn, D.S. Wainwright // *Science*. – 1994. - 264. – P. 1115-1118

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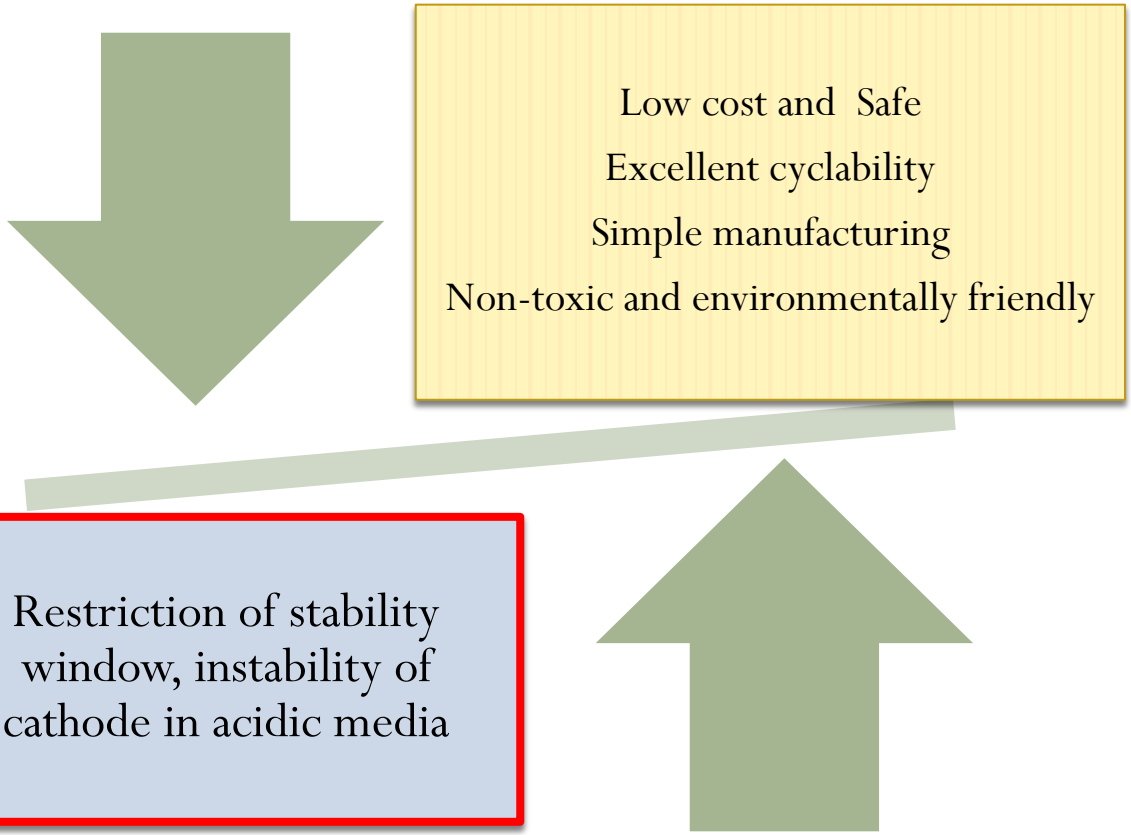
Advantages of RALBs



How to balance between these two?

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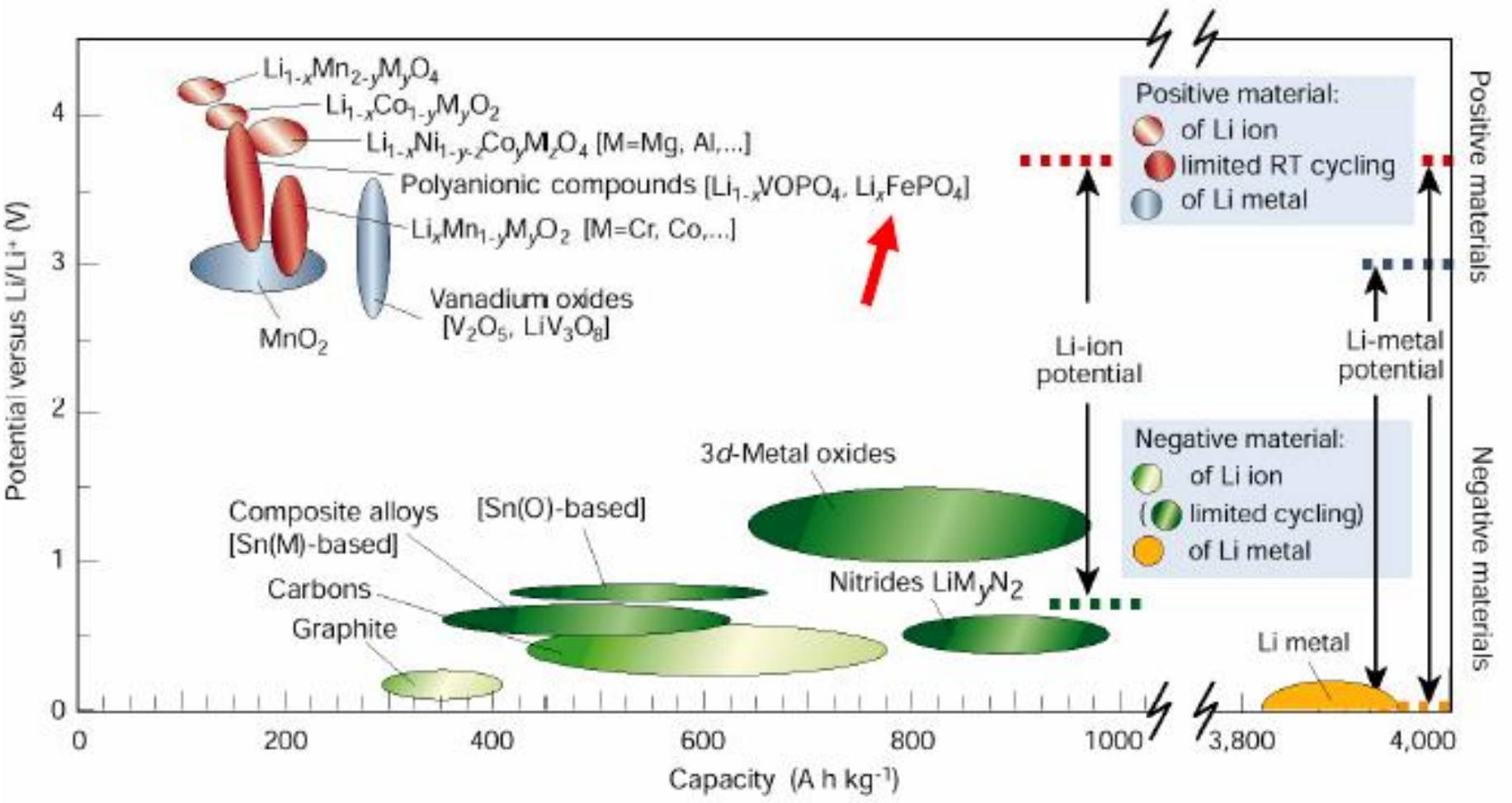
Choice of materials in 'traditional' LIBs



J.-M. Tarascon and M. Armand , Nature, 414, 359, 2001

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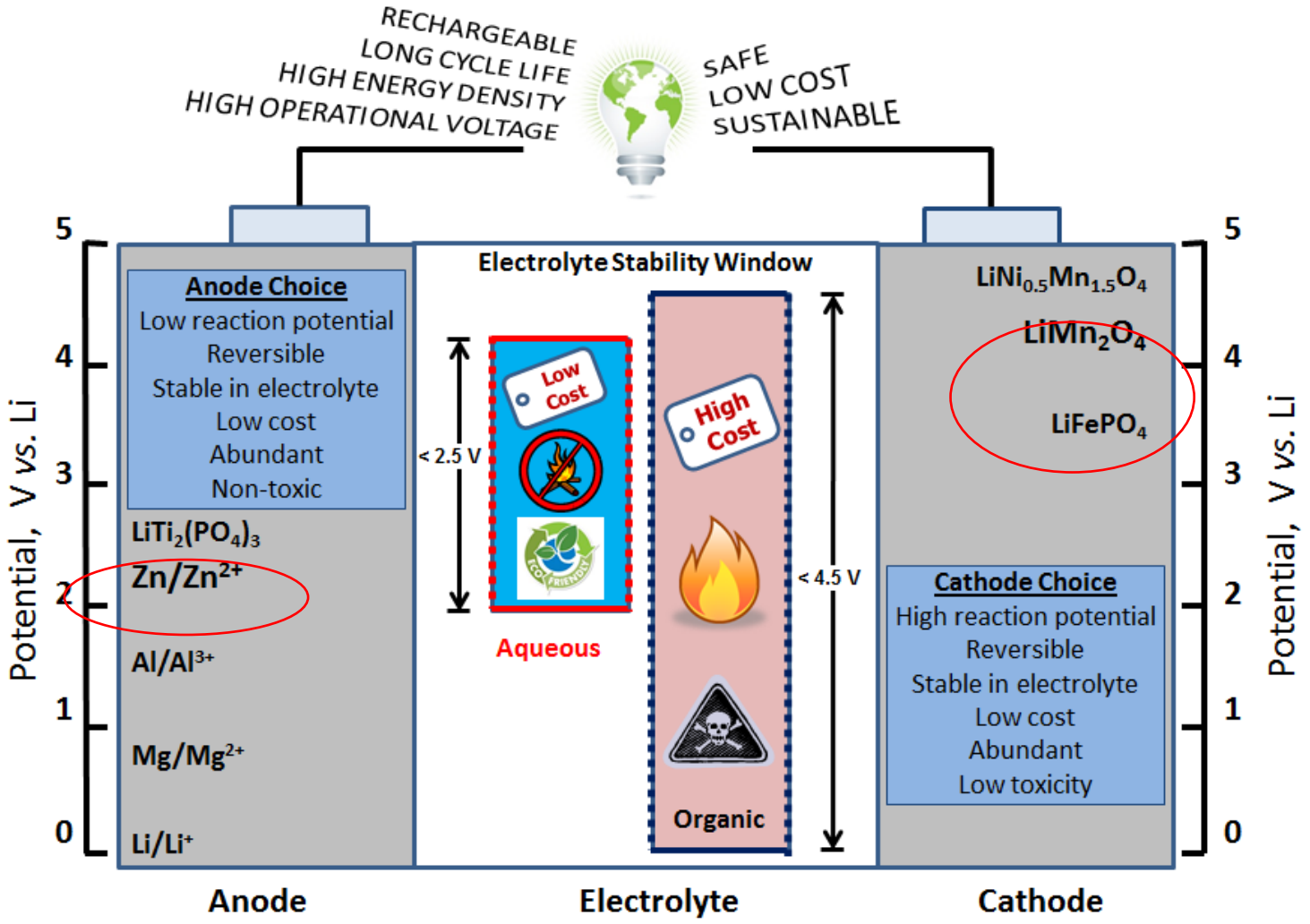
Materials choice for RALB



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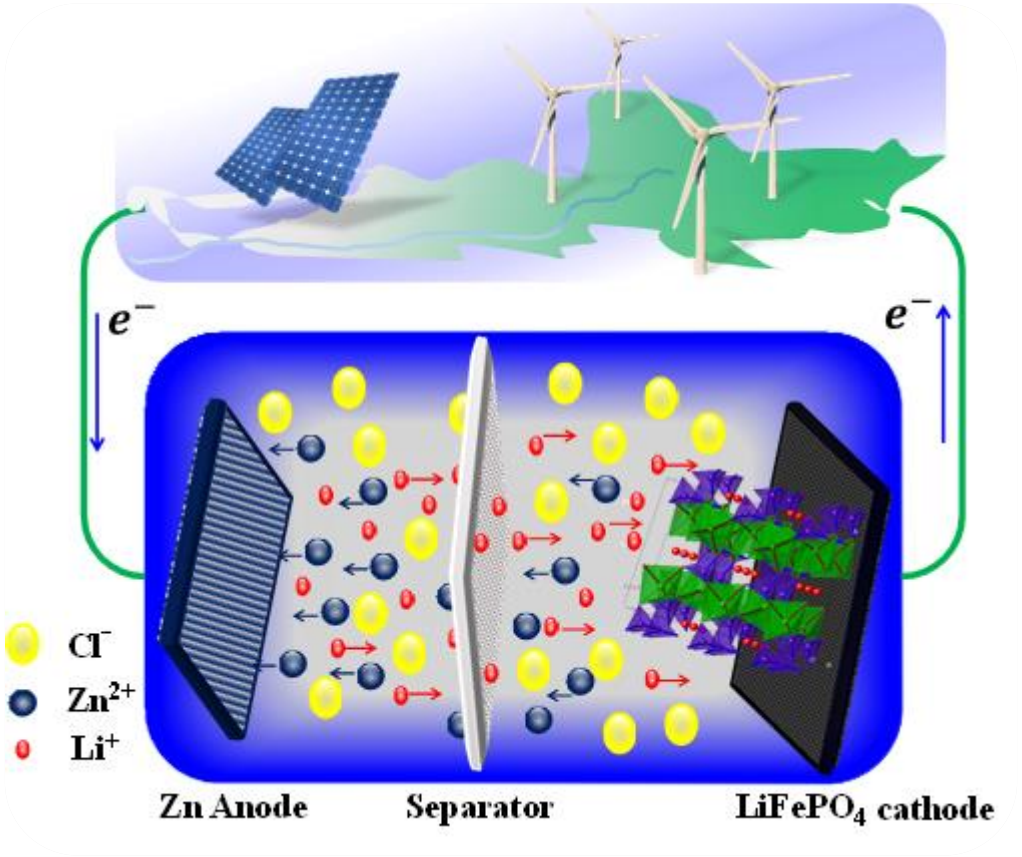
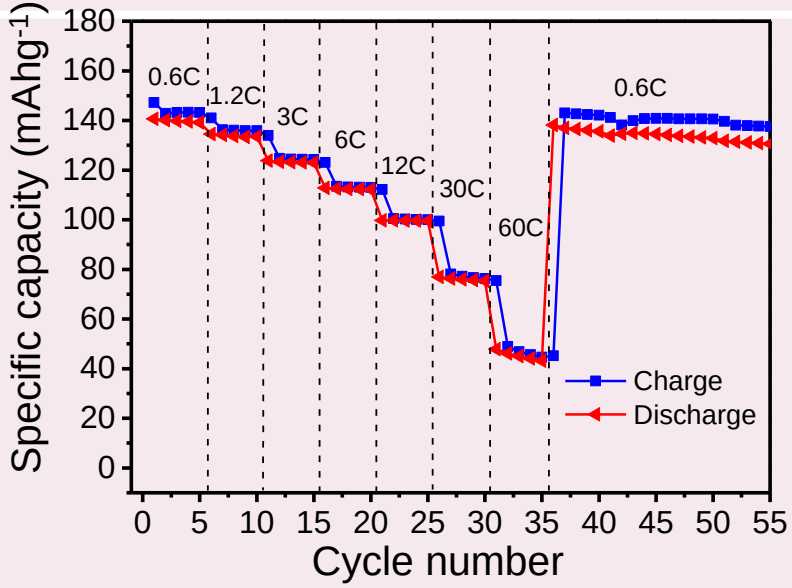
RALB Zn/$LiFePO_4$

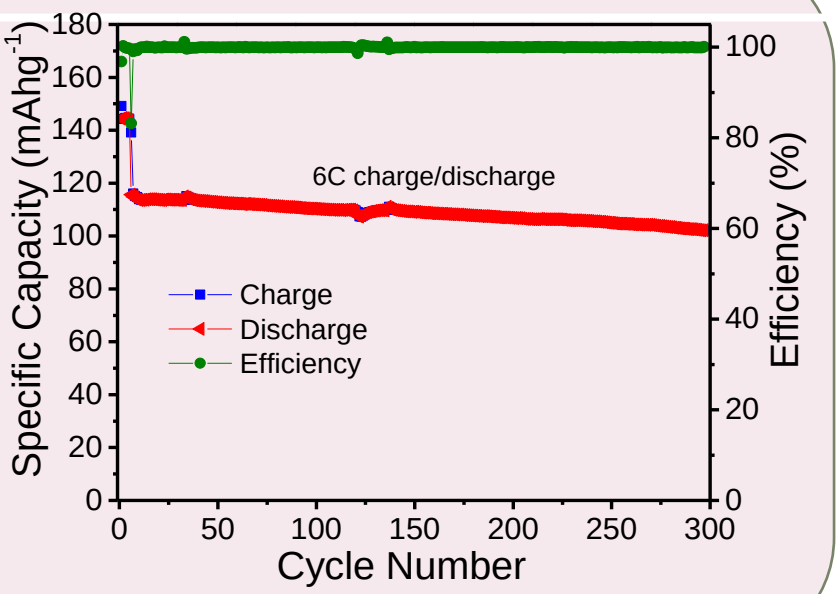


Dual/hybrid electrolyte:

- 3 mol dm^3 LiCl and
- 4 mol dm^3 $ZnCl_2$

cell)





Superior rate capability

- 75 $mAhg^{-1}$ at 30 C and 42 $mAhg^{-1}$ 60 C,
- 6 C: at 200 and 400 cycles, capacity retention is 95% and 82%.

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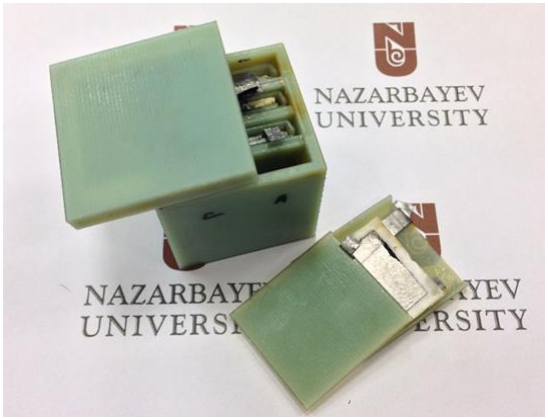
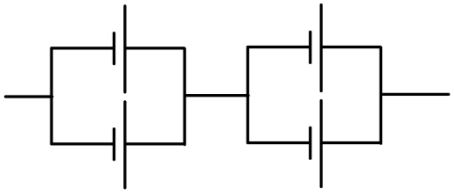
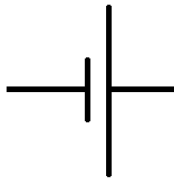
Large Scale batteries



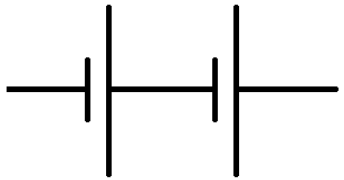
Development of battery module



2.4V, 100 mAh



1.2V, 2,000 mAh



12V, 10,000 mAh

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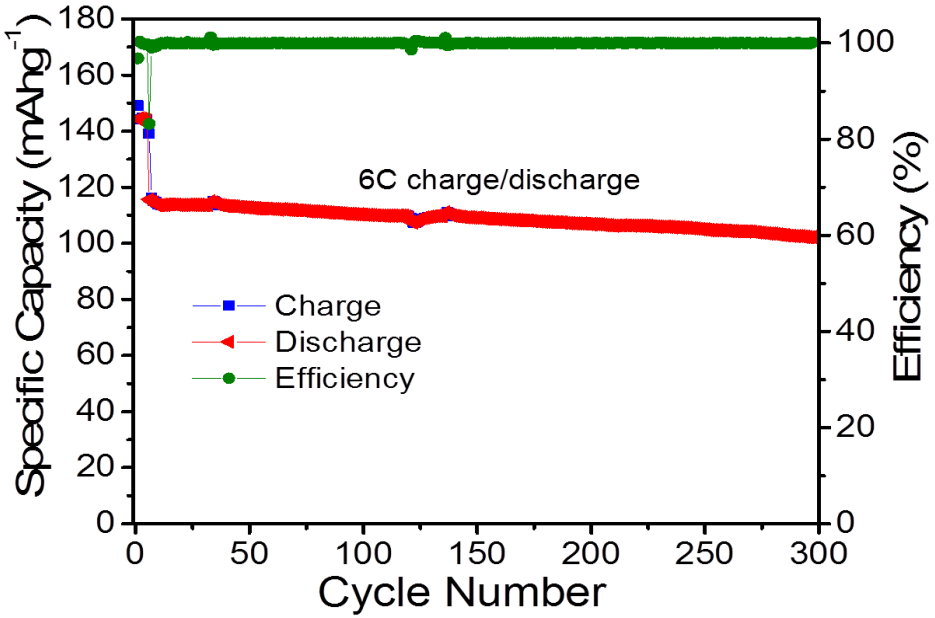
Current state of development

- The batteries were tested in laboratory scale and showed excellent performance:
  - Pouch cells of 1 Ah capacity – 300 cycles with 85% capacity retention and 100% energy efficiency at 6 C rate (full charge and discharge in 10 min!).
- **Currently the batteries are under testing in various devices.**



Cyclability of RALB 300 cycles with 85% capacity retention and 100% efficiency.

Electrochimica Acta, 152 (2015) 505-511

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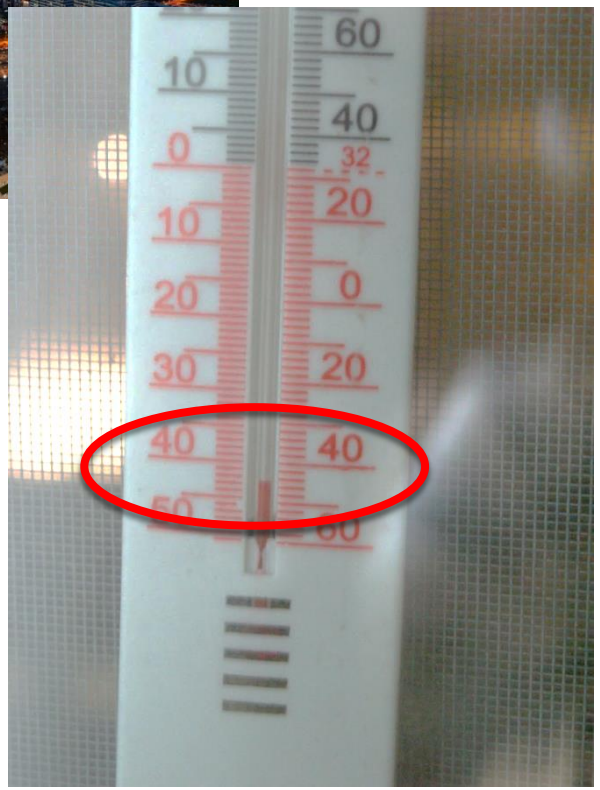

However…

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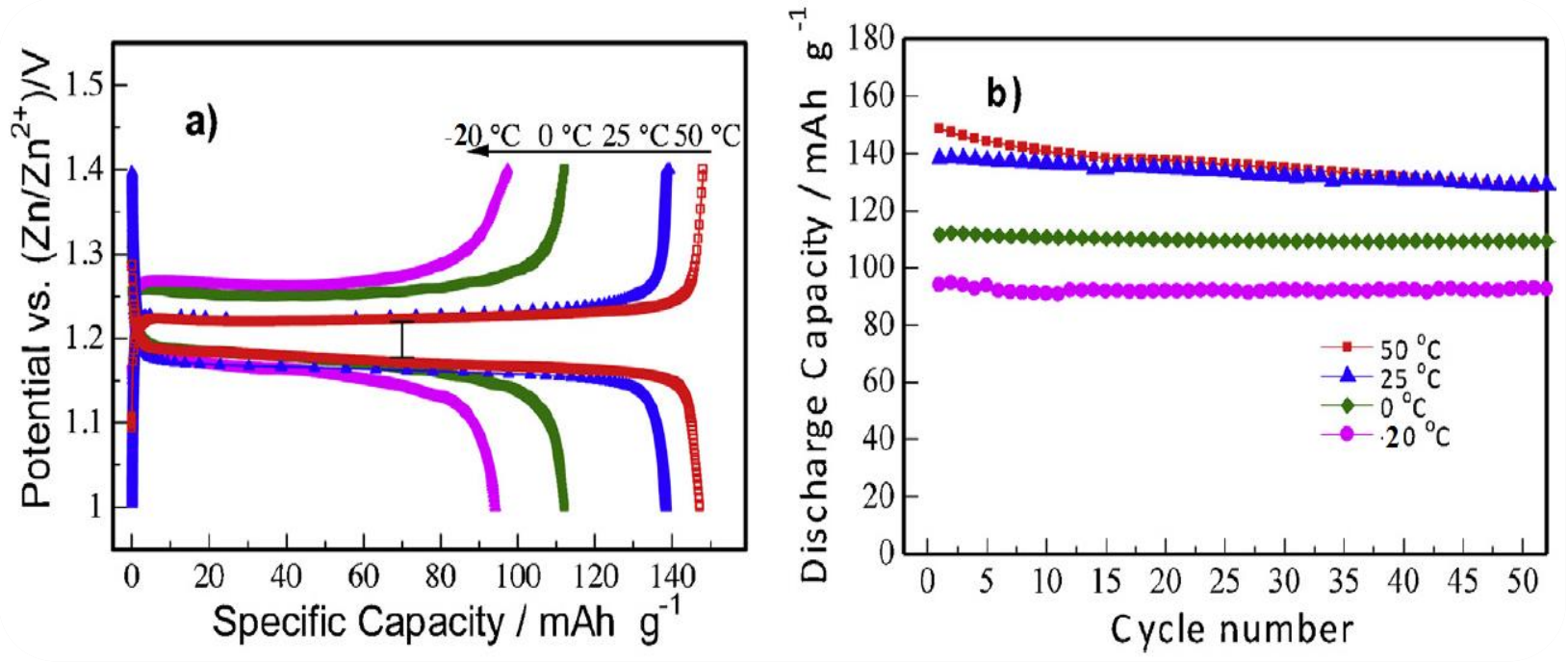
Temperature investigation of RALB



From -20 ◦C to 50 ◦C

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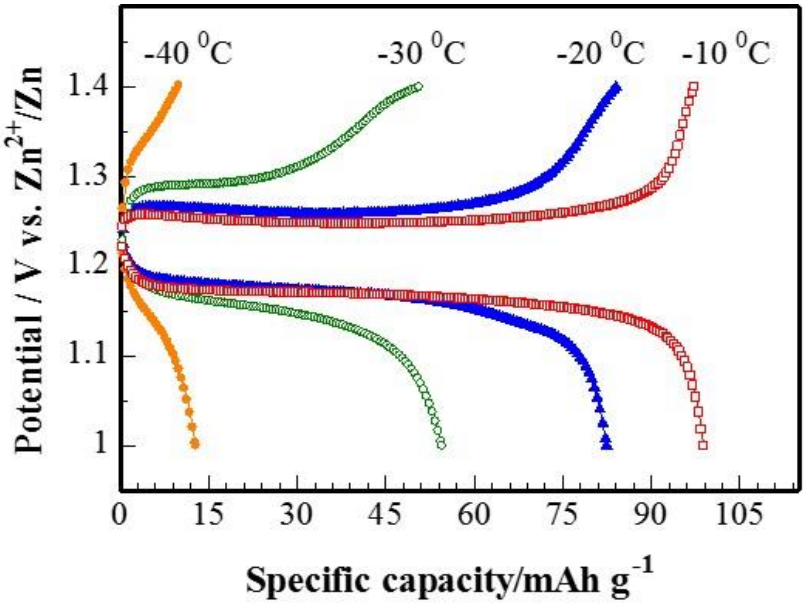
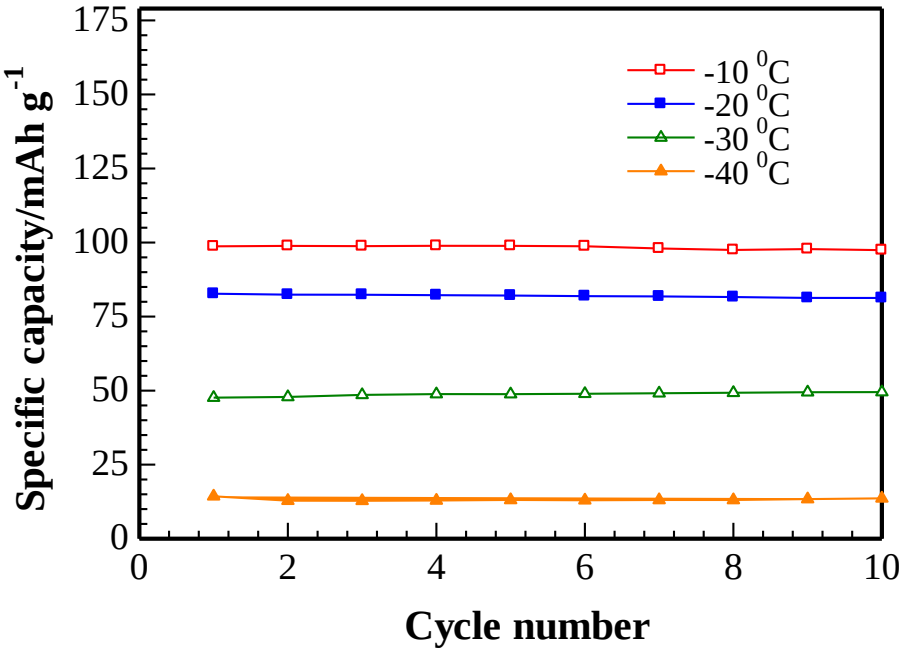
Low temperature performance of RALB





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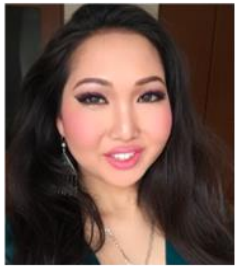
Advanced Energy Storage Systems and Functional Nanomaterials Research Group

Prof. Zhumabay Bakenov (TokyoTech)

Dr. Indira Kurmanbayeva (TokyoTech)

Dr. Almagul Mentbaeva (al-Farabi KNU)

Prof. Moulay-Rachid Babaa (Morocco, France)



Dr. Anara Molkenova (TokyoTech)

Prof. Desmond Adair (UK)

Prof. Teyeb Ould Ely (USA)

Dr. Assiya Yermukhambetova (UCL, UK)

Prof Yongguang Zhang (China)

Dr. Kairat Ismailov (TokyoTech)

Prof. Mohamed Bouhrara (Morocco, France)

Dr. Arailym Nurpeissova (Chungnam National University)

Dr. Kuralay Korzhynbayeva (al-Farabi KNU)

Dr. Renat Tussupbayev (TokyoTech)

… total more than 45 members…

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Recent Publications, 2010-2015

- A. Konarov, Z. Bakenov, H. Yashiro, Y.K. Sun, S.T. Myung, ***Journal of Power Sources***, 355 (2017) 140-146.
- F. Yin, X. Liu, Y. Zhang, Y. Zhao, A. Mentbayeva, Z. Bakenov, X. Wang, ***Solid State Sciences***, 66 (2017) 44–49.
- A. Yermukhambetova, C. Tan, S. R. Daemi, Z. Bakenov, J.A. Darr, D.J.L. Brett, P.R. Shearing, ***Scientific Reports***, 6 (2016) Art. #35291.
- A. Mentbayeva, A. Belgibayeva, N. Umirov, Y. Zhang, I. Taniguchi, I. Kurmanbayeva, Z. Bakenov, ***Electrochim. Acta***, 217 (2016) 242–248.
- A. Yermukhambetova, Z. Bakenov, Y. Zhang, J.A. Darr, D.J.L. Brett, P.R. Shearing, *J. Electroanalyt. Chem.*, 780 (2016) 407-415.
- Y. Zhang, Y. Li, H. Li, Y. Zhao, F. Yin, Z. Bakenov, ***Electrochim. Acta*** 20 (**2016**) 475–483.
- G. Yuan, Y. Zhao, H. Jin, Z. Bakenov, *Ionics* 22 (**2016**) 1819-1827. DOI 10.1007/s11581-016-1729-7.
- H. Li, Y. Wei, Y. Zhang, F. Yin, C. Zhang, G. Wang, Z. Bakenov, *Ionics* 22 (**2016**) 1387-1393.
- L. Huang, X. Wang, F. Yin, Y. Zhang, J. Gao, J. Liu, G. Zhou, Z. Bakenov, ***Int. J. Electrochem. Sci***., 11 (2016) 8439 – 8446.
- H. Li, Y Li, Y. Zhang, C. Liang, H. Wang, B. Li, D. Adair, Z. Bakenov, ***Nanoscale Research Letters*** 11 (2016) 432.
- H. Li, Y. Wei, Y. Zhang, C. Zhang, G. Wang, Y. Zhao, F. Yin, Z. Bakenov, Ceramics International 42 (**2016)** 12371-12-377.
- Y. Zhang, Y. Li, H. Li, F. Yin, Y. Zhao, Z. Bakenov, *J. Nanopart. Res.* 18:63 (**2016**).
- K. Ismailov, D. Adair, Y. Massalin, Z. Bakenov, *Heat Mass Transfer* (**2016**) 1-10.
- H. Li, Y. Wei, Y. Zhao, Y. Zhang, F. Yin, C. Zhang, Z. Bakenov, *J. Nanomater.* 2016 (**2016**), Article ID 4675960, 6 pages, doi:10.1155/2016/4675960.
- G. Yuan, F. Yin, Y. Zhao, Z. Bakenov, G. Wang, Y. Zhang, *Ionics* 22 (**2016**) 63–69.
- Y. Zhao, X. Liu, F. Yin, Z. Bakenov, Y. Zhang, *Electrochemistry*, 84 (1) (**2016**) 7–11.

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Conclusions

- In rechargeable batteries
  - Ecologically friendly and safe aqueous batteries have been developed for large scale applications
- Our Group is interested in cooperation on
  - Materials preparation and characterization,
  - Development of modeling and simulation research,
  - Development of in-situ techniques.

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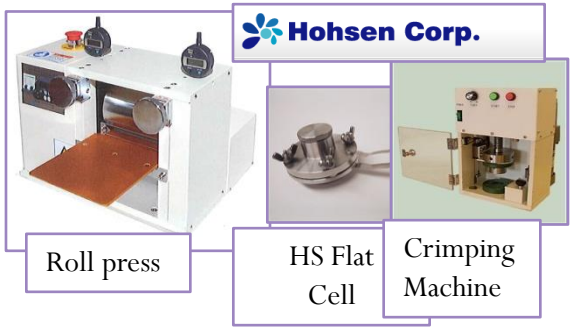
Pouch cell assembling and testing

Vacuum mixing → Electrode Coating → Dry and roll press → Cutting → Electrode stacking → Welding → Electrolyte injection and Sealing in glovebox → Vacuum sealing → Battery testing

Major Equipment

Elementar Vario Micro Cube



Rigaku SmartLab

MBraun LabMaster

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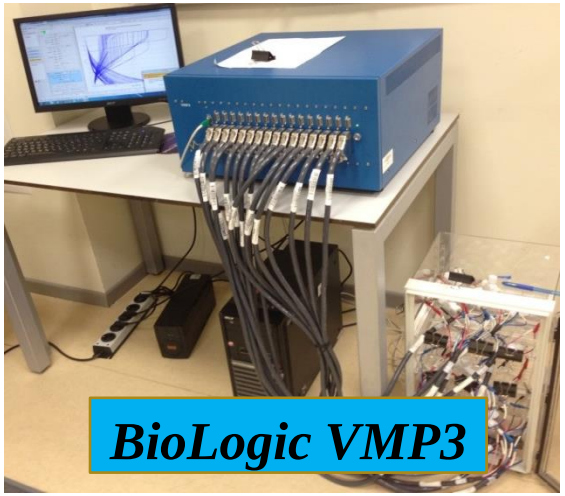
Electrochemical characterization

CR2032 coin cells



BioLogic VMP3

Pouch cells

Arbin BT2000

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THANK YOU VERY MUCH FOR YOUR ATTENTION !

batterykazakhstan.com