Advanced Materials for Energy Roadmap

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Outline

- 1. EMIRI association and energy storage R&I program.
- 2. SET Plan-10 targets and key actions.
- 3. Action 7 e-mobility/storage - KPI targets.
- 4. Roadmap Li Ion batteries.
- 5. Battery systems beyond Li-ion.
- 6. Printed batteries.
- 7. Cost perspectives Li Ion.

1. EMIRI Association works for the future of Advanced Materials for low carbon energy (LCE) in Europe

EMIRI
Bridging the Innovation Gap

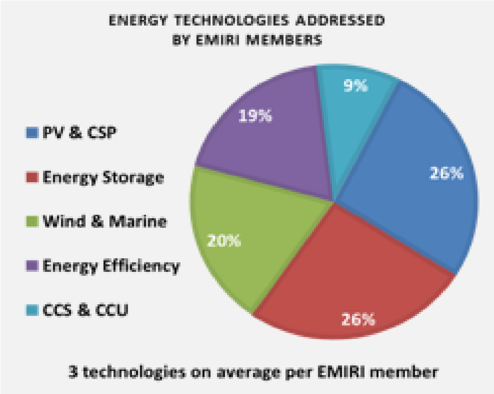
EMIRI is an Industry Community coming together …

* Founding / current members

Supported by Research & Technology Organizations

With key Associations bringing in their expertise

Spanning Innovation & Manufacturing

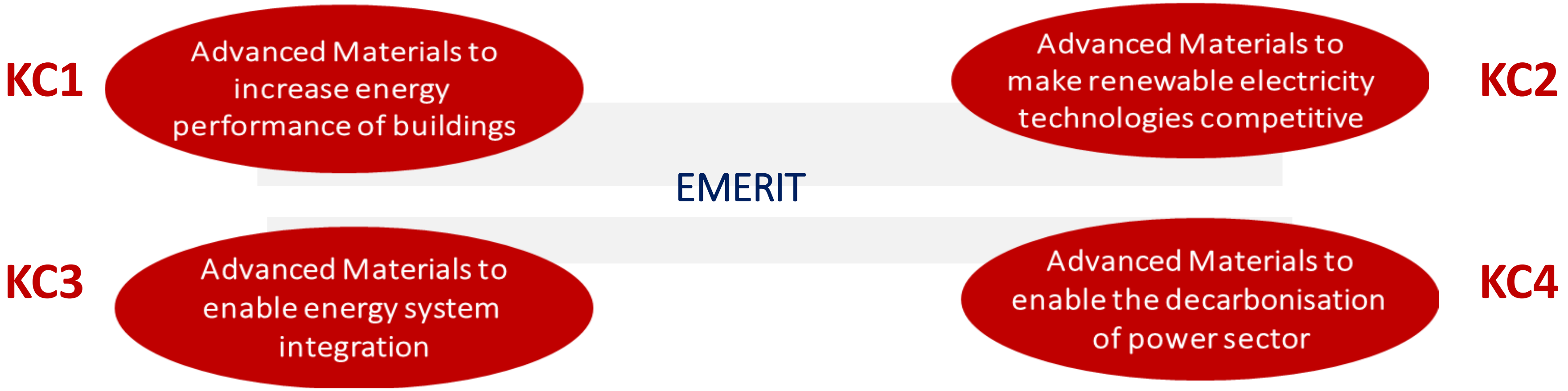


- Presence in 19 EU countries
- Over 80 innovation centers
- Over 50 manufacturing sites

* Advanced Materials such as steel, non-ferrous metals, alloys, glass, ceramics, polymers, composites …

The Industry-Driven Initiative promoted by EMIRI calls for prioritization & action in R&I on Adv. Materials

- Following collaboration of EMIRI members (Industry, Research Organizations, Associations) with DG R&I (Key Enabling Technologies), a focused R&I program on Advanced Materials for LCE was defined
- The R&I program is the backbone of the **Industry-Driven Initiative (IDI)** called **EMERIT** (Energy Materials for Europe – Research & Industry innovating Together)
- The IDI focusses on 19 topics (in range of TRL 4-7) spread over **4 key components** addressing the challenges of the European Energy System … and contributing to relevant actions listed in the SET Plan Integrated Roadmap document
- **The IDI aims at bridging the gap between lab and market in Advanced Materials, reducing innovation risks and accelerating innovation in Advanced Materials to enable faster development of low carbon energy technologies**



Among 19 topics promoted by EMIRIT IDI, 5 **energy storage** related topics are of interest to support Action 4 of Integrated SET Plan.

Key Component 3 **Advanced Materials to enable energy system integration**			**Research & Innovation Actions**	**Innovation Actions**
			TRL 4 - 6	**TRL 5 - 7**
K3-I1	Innovation Topic #1	Advanced Materials for lower cost, high safety, long cycle life & environmentally friendly electrochemical batteries - Li- ion batteries		
K3-I2	Innovation Topic #2	Advanced Materials for lower cost, high safety, long cycle life & environmentally friendly electrochemical batteries - Next generation electrochemical batteries		
K3-I3	Innovation Topic #3	Advanced Materials for lower cost storage of energy in the form of hydrogen or other chemicals (power to gas, power to liquid technologies)		
K3-I4	Innovation Topic #4	Advanced Materials to facilitate the integration of storage technologies in the grid		
K1-I5	Innovation Topic #5	Advanced Materials for thermal energy storage (TES) - Next generation thermal energy storage technologies		

Brief project description- Example

- **K3-I1 – Advanced Materials for lower cost, high safety, long cycle life & environmentally friendly electrochemical batteries (Li-ion batteries) (Innovation Actions)**
- Optimization of Li-ion batteries for low cost, high safety and long cycle life requires the development of Advanced Materials for electrodes (cathode, anode), electrolytes, binders and optimized packaging (new and lighter composites) materials. These Advanced Materials can lead to improved stationary Li-ion batteries with well specified KPIs for energy and power density, extended lifetime and significantly improved cost (target below 0.05 euro/kWh/cycle) while offering full safety. Typical cathode materials can be improved or novel LPF and NMC types with current or increased voltages. Typical anode materials can be improved graphite or micron/nano-sized Si, Sn composites… Also electrolyte materials will need to be stable at higher voltages and the same prevails for novel separator materials. Hybridization of Li-ion batteries with supercapacitors can contribute to power and life performance. Solid-state developments by polymer or solid electrolytes may lead to higher safety levels. All Advanced Materials priorities will need to smartly combine low cost, high energy density and long cycle life.

Brief project description- Example

Key Component 3 - Advanced Materials to enable energy system integration	
K3-I1	**Advanced Materials for lower cost, high safety, long cycle life & environmentally friendly electrochemical batteries (Li-ion batteries) (Innovation Actions)**
Innovation Challenges	By the development of advanced functional particles, filaments, layers, coatings and new chemistries, innovation should be focused on the optimization of Li Ion batteries for low cost, high safety, long cycle life, extreme use and environmentally friendly storage stationary applications .Li Ion batteries are indeed planned to become major storage components dedicated to the storage of renewable energy in power and energy steering applications. However, successful marketing requires first improvement in cyclability, reliability, usage (ease of metrology of SoC, SoH …) and lifetime.
Activities	New chemistries of electrode materials and electrolyte as well as optimized packaging of the cell and module must be implemented to provide improvement in the ESS application in line with durability. For stationary applications, the ageing behavior is also an issue that needs specifically to be addressed. Representative ESS ageing protocols must be developed in relation to standards and modelling of the ageing phenomenon. Moreover, Li-ion battery production must be developed in an environmentally friendly way: an NMP-free process is required in line with REACH directives, large-scale new materials manufacturing processes need to be developed to reduce the battery cost. Safety will be addressed by the choice of materials and/or configuration of the system. Hybridization of Li Ion batteries with super capacitors (improved by Advanced Materials) (LiC type) is also considered. Synergies with higher energy density flywheels can be explored. Development and assessment of a representative module size of min 5kWh is required: a 3 to 4 years research project is expected including fundamental research and relevant industrial R&D.
Expected Outputs	New or improved cathode, anode, electrolyte, binder and packaging materials leading to improved stationary Li Ion batteries with well specified KPI's for energy and power density, with extended lifetime and significantly improved cost (target <0.05€/kWh/cycle) and at the same time fully safe.

Brief project description- Example

- **K3-I2 - Advanced Materials for lower cost, high safety, long cycle life & environmentally friendly electrochemical batteries (next generation electrochemical batteries) (Research & Innovation Actions)**
- Innovation is here driven by the same needs as those outlined in K3-I1 but is dealing with new alternative storage solutions compared to the current battery storage systems. The wide range of new candidate systems covers among others metal-air, lithium- sulfur, new ion-based systems (Na, Mg or Al), redox flow batteries (free of Vanadium). Advanced Materials developed herein can cover cathodes, anodes, electrolytes, separators, binders …

Brief project description- Example

Key Component 3 - Advanced Materials to enable energy system integration	
K3-I2	**Advanced Materials for lower cost, high safety, long cycle life & environmentally friendly electrochemical batteries (next generation electrochemical batteries) (Research & Innovation Actions)**
Innovation Challenges	Innovation is related to new alternative storage solutions to the current battery storage systems (which are Li-Ion, sodium sulphur (Na-S), lead acid, Ni based systems or Vanadium Flow batteries as reference base) and prove their positive impact in the implementation of renewable energy. The wide range of new candidate systems with among others Metal-Air, Li-S, new Ion based systems (Na, Mg, or Al), Redox Flow Batteries (V- free)..., need to be explored and by the right development of Advanced Materials and systems brought to TRL 6 level. The deployment of the new energy storage system must be done in view to target low cycle cost, with a reliable efficiency, safety and lifetime.
Activities	Ageing behavior must be understood for the specific application of ESS with intermittent energy supply and demand. Modularity and hybridization must be developed to contribute to a better component use for dynamic application and improved lifetime of the ESS.A full LCA and economic cost study must been done in comparison to the current ESS solution. Development and assessment of a representative module size of min 5 kWh is required. A 3-4 years research project is expected including fundamental research and relevant industrial R&D
Expected Outputs	New or improved cathode, anode, electrolyte, binder and packaging materials leading to stationary new generation batteries with well specified KPI's for energy and power density, with extended lifetime and significantly improved cost (target <0.05€/kWh/cycle) and at the same time fully safe.

Bridging the Innovation Gap

KPI's

Advanced Materials to enable energy system integration		KPI	2020	2025	Beyond
K3-I1	Advanced Materials for lower cost, high safety, long cycle life & environmentally friendly electrochemical batteries (Li-ion batteries)	Gravimetric energy density	200 Wh / kg	350 Wh / kg	400 Wh / kg
		Volumetric energy density	600 Wh / l	800 Wh / l	> 800 Wh / l
		Power density	2 - 3 kW / kg	5 kW / kg	> 10 kW / kg
		Lifetime (number of cycles)	3000 cycles 80% DOD	10.000 cycles 80% DOD	15.000 cycles 80% DOD, > 20 yrs
		Safety	Safe -10°C, +60 °C (normalized tests)	Safe -20°C, +70 °C (normalized tests)	Safe < - 20°C, > +70 °C (normalized tests)
			Safety system implemented	Tests Stallion/Stabalid fully met	Tests Stallion/Stabalid fully met
		Cost	< 0.1 euro / kWh / cycle	< 0.05 euro / kWh / cycle	< 0.05 euro / kWh / cycle
		LCA & recycling	Developed	Fully established	Fully established
		Demo installed	MW scale (de)centralized	MW scale (de)centralized	MW scale (de)centralized
		P/E ratio (for energy based system)	< 3	<3	<3
		P/E ratio (for power based system)	> 15	> 15	> 15
		Advanced Materials for LiC supercapacitors			
		Gravimetric energy density	35 Wh / kg	40 Wh / kg	50 Wh / kg
		Power density	10 kW / kg	15 kW / kg	20 kW / kg
		Cycle life	1M cycles	1.5M cycles	2M cycles
		Temperature window	- 20 °C, + 70 °C	- 40 °C, + 90 °C	- 40 °C, + 90 °C

2. SET Plan-10 targets and key actions

SET Plan Integrated Roadmap (13 themes)	ENERGY UNION R&I & Competitiveness priorities	SET Plan (10 key actions)
T10: Development of renewables T8: System flexibility	N°1 in Renewables	1. Performant renewable technologies integrated in the system 2. Reduce costs of technologies
T1: Engaging consumers T2: Smart technologies for consumers T6: Modernising the electricity grid T7: Energy storage T8: System flexibility T9: Smart cities & communities	Smart EU Energy System with consumers at the centre	3. New technologies & services for consumers 4. Resilience & security of energy system
T3: Energy efficiency in buildings T4: Energy efficiency in heating & cooling T5: Energy efficiency in industry & services	Efficient Energy Systems	5. New materials & technologies for buildings 6. Energy efficiency for industry
T7: Energy storage T13: Biofuels, fuel cells & hydrogen, alternative fuels	Sustainable Transport	7. Competitive in global battery sector (e-mobility) 8. Renewable fuels
T11: Carbon capture storage/use		9. CCS/U
T12: Nuclear energy		10. Nuclear Safety

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3. Action 7 e-mobility/storage - KPI targets (1)

		Current (2014/ 2015)	2020	*2030
Performance targets for automotive applications unless otherwise indicated				
1	Gravimetric energy density [Wh/kg]			
	pack level	85-135	235	> 250
	cell level	90-235	350	> 400
2	Volumetric energy density [Wh/l]			
	pack level	95-220	500	> 500
	cell level	200-630	750	> 750
3	Gravimetric power density [W/kg]			
	pack level	330-400	470	> 470
	cell level		700	> 700
4	Volumetric power density [W/l]			
	pack level	350-550	1.000	> 1.000
	**cell level		1.500	> 1.500
5	Fast recharge time [min] (70-80% ΔSOC)	30	22	12
6	Battery life time (at normal ambient temperature)			
	Cycle life for BEV*** to 80% DOD [cycles]		1.000	2000
	Cycle life for Stationary to 80% DOD [cycles]	1000-3000	3000-5000	10000
	Calendar life [years]	8-10	15	20

*: Post-Lithium ion technologies are assumed relevant in this time frame
**: May also be relevant to stationary applications
*** Cycle life for PHEV must be bigger

Action 7 e-mobility/storage - KPI targets (2)

TARGETS		Current (2014/ 2015)	2022	2030
Cost target				
1	Battery pack cost for automotive applications [€/kWh]	180-285	90	75
2	Cost for stationary applications requiring deep discharge cycle		0,1	0,05

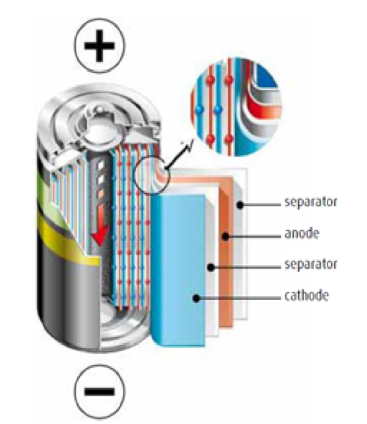
Action 7 e-mobility/storage - KPI targets (3)

	TARGETS	Current (2014/ 2015)	2020	2030
Manufacturing targets				
1	Automotive (Li-ion and next generation post-lithium) battery cell production in EU [GWh/year][1] (% supporting EU PHEV+BEV production)	nearly 0	5 (50% of the 0.5 M EVs with 20 kWh)	50 (50% of the 2 M EVs with 50 kWh)
2	*Utility Storage (Li-ion and next generation post-lithium) battery cell production in EU [GWh/year]		2.2	10
3	Recycling			
	Battery collection rate	45% (Sept 2016)	70%	85%
	Recycling efficiency (by average weight)	50%	50%	50%
	Economy of recycling	Not economically viable	Break even	Economically viable
4	Second Life	Not developed	Developed	Fully established

4.Roadmap Li Ion batteries

NiMH (1.2V)	→	Li-Ion (~3.8V)	→	Advanced Li-Ion (3.8V-5.0V)	→	New Systems

Current Li-ion battery materials

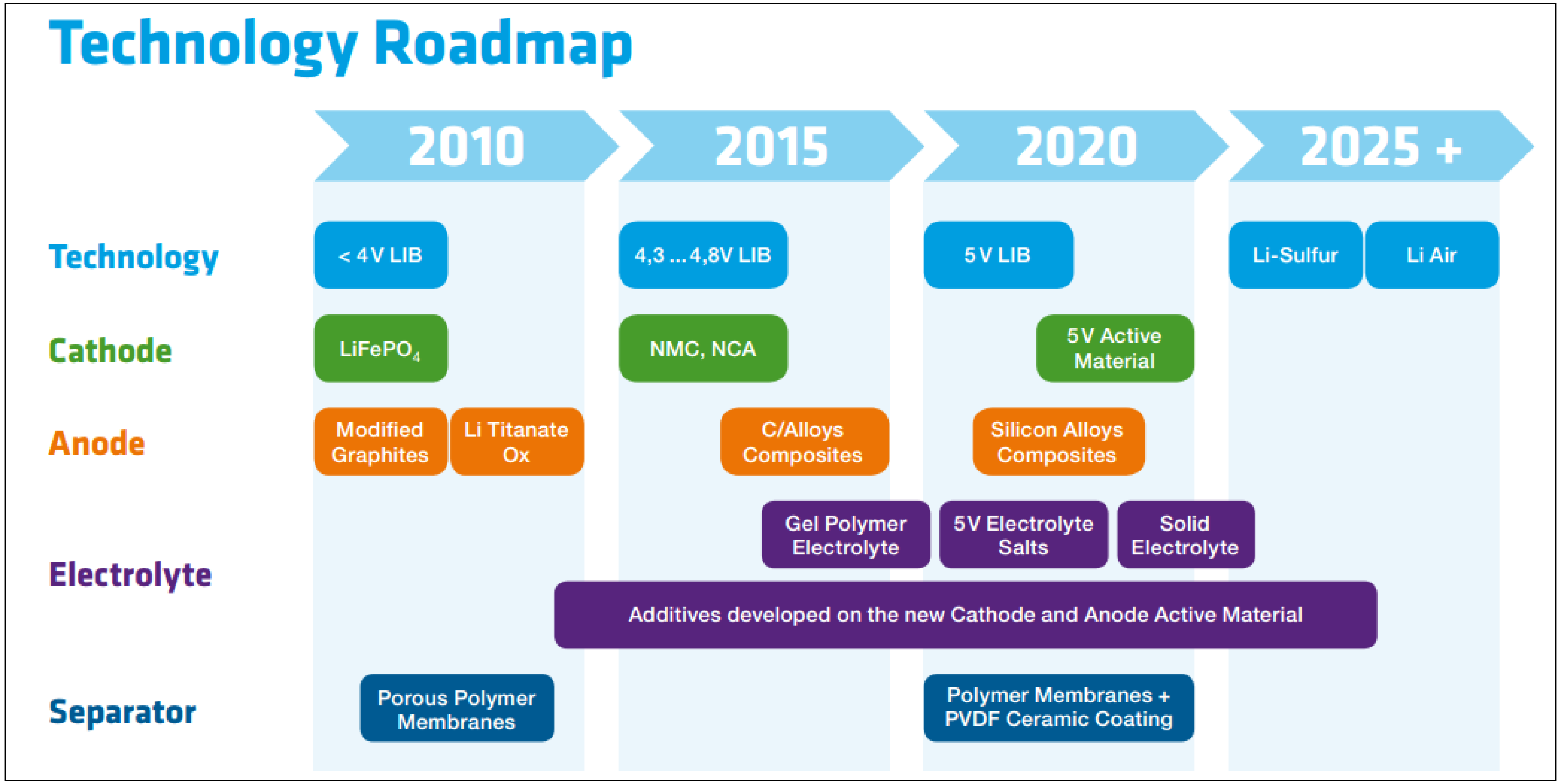


- Anode (= negative)
  - graphite/carbon
- Separator
  - Ion permeable inert membrane
- Cathode (= positive)
  - Lithium cobaltite and new generation materials
- Electrolyte
  - Liquid or gel

Charge: Li-ions from cathode to anode

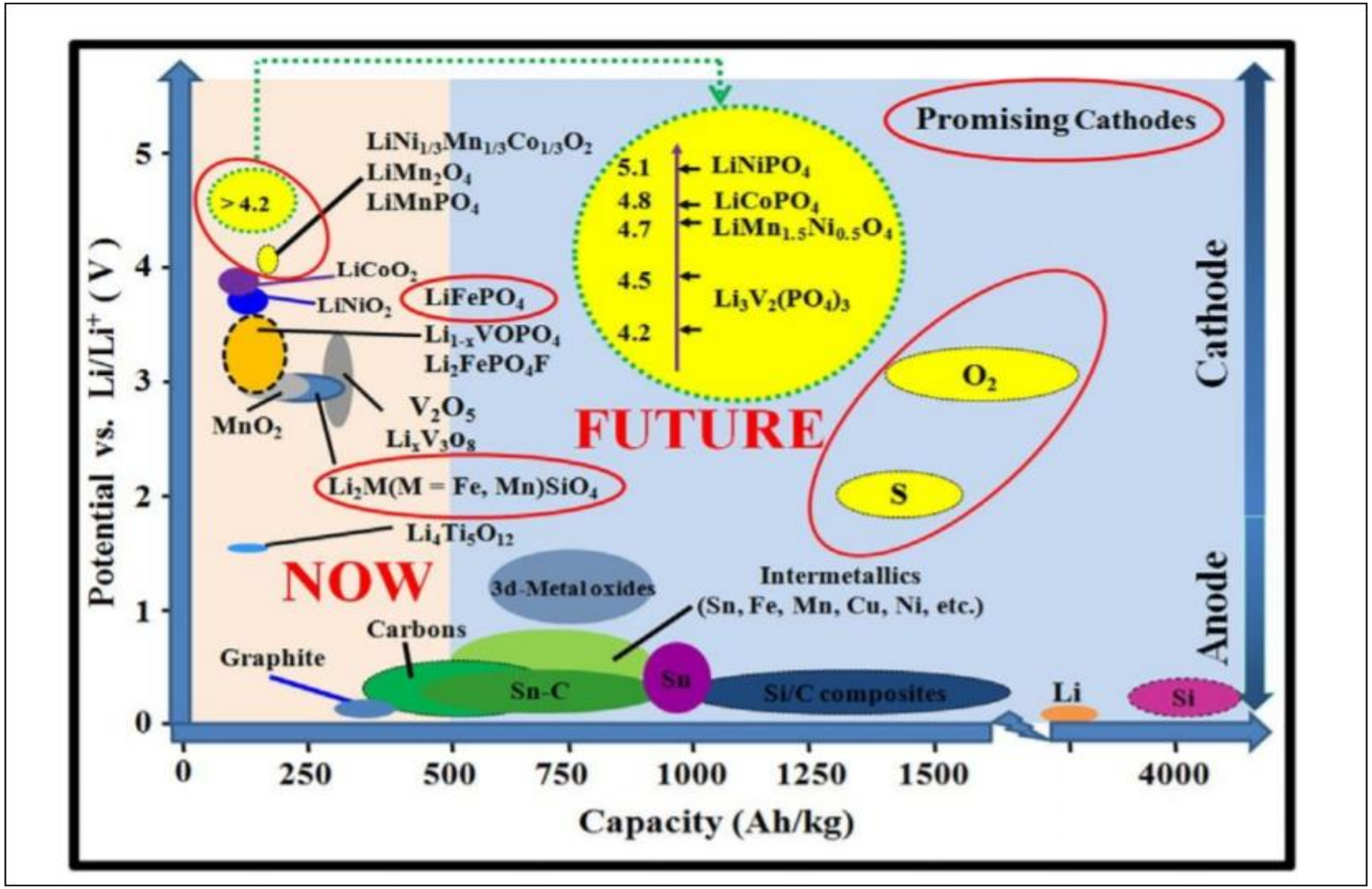
Discharge: Li-ions from anode to cathode

Future evolution to higher voltage battery systems



Solvay R&I

Developments 5V cathode materials: www.fivevb.eu

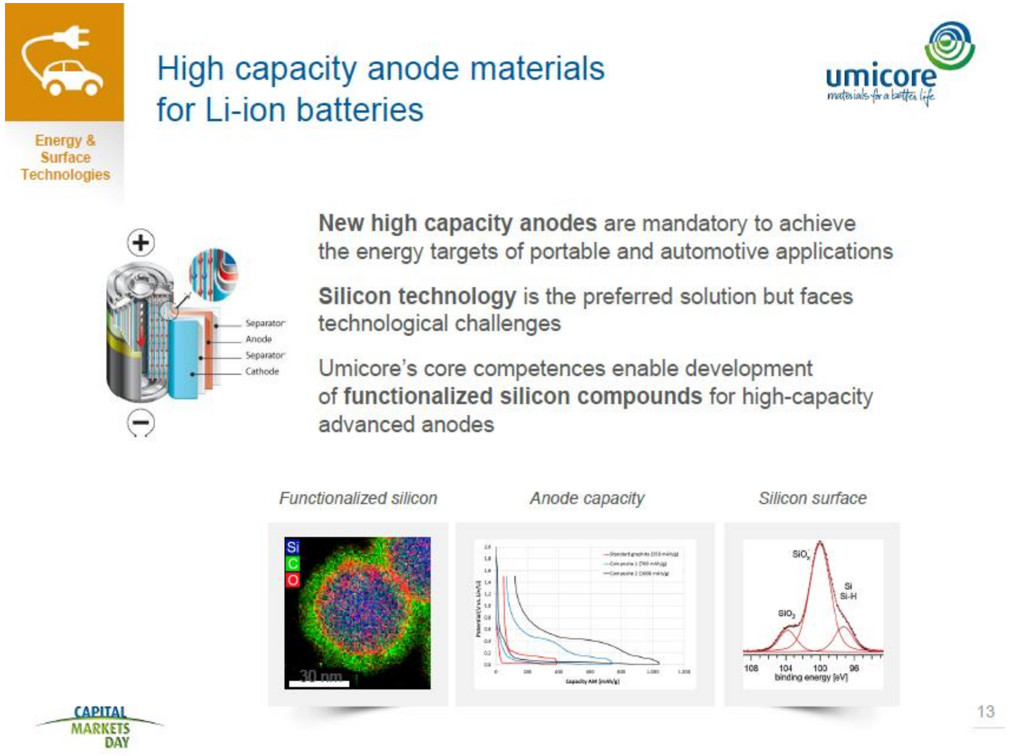


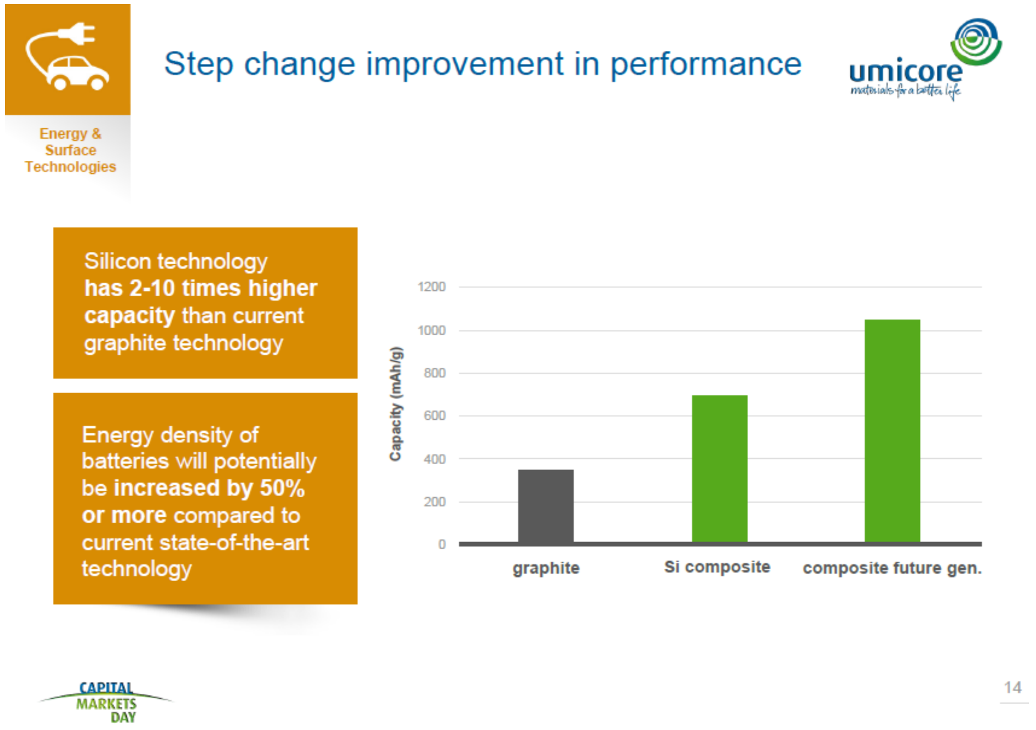
Xu, J. T.; Dou, S. X.; Liu, H. K.; Dai, L. M. Nano Energy 2013, 2, 439

Paired with high capacity novel anode materials

www.spicy-project.eu
www.sintbat.eu

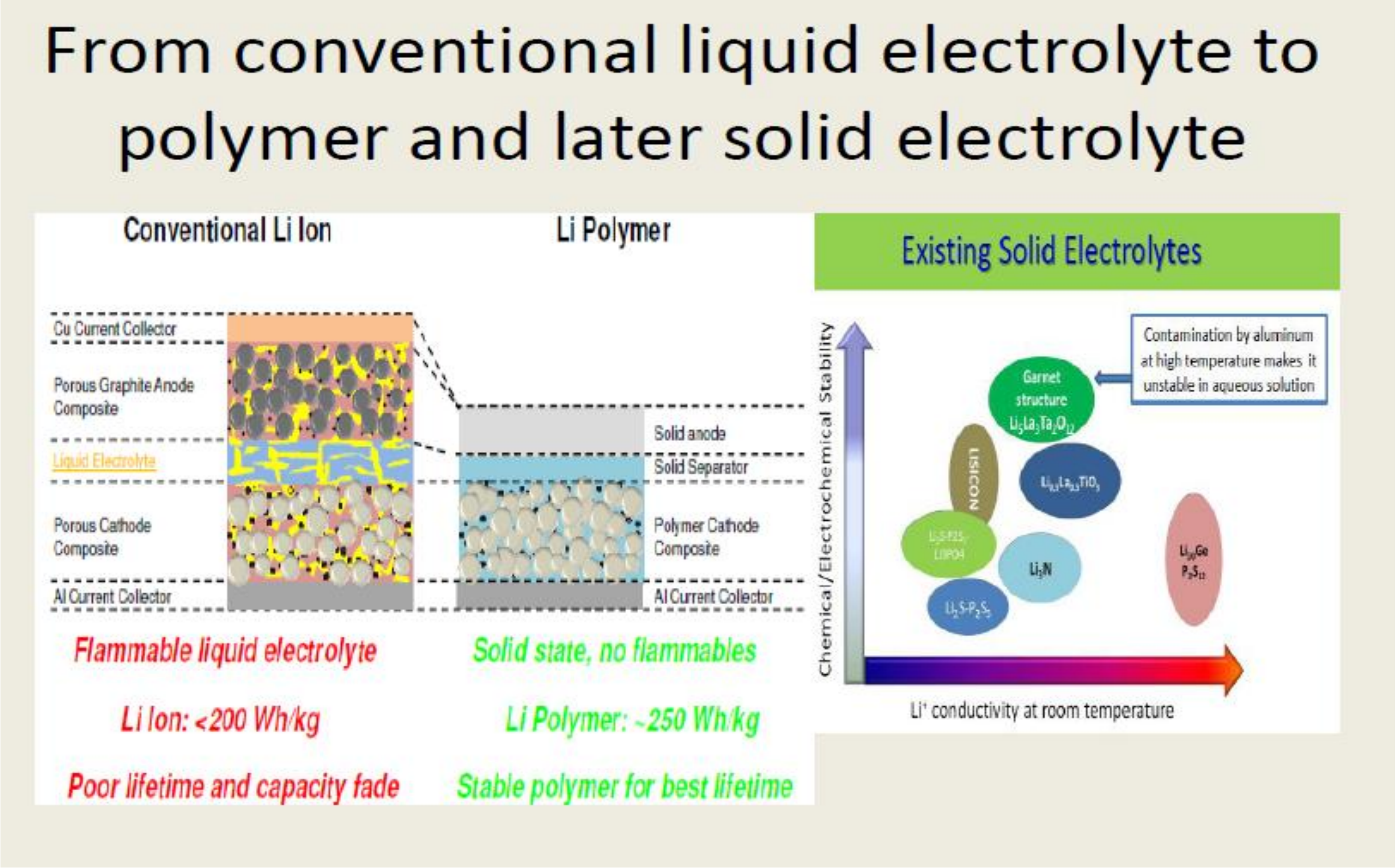
- Si/C composites



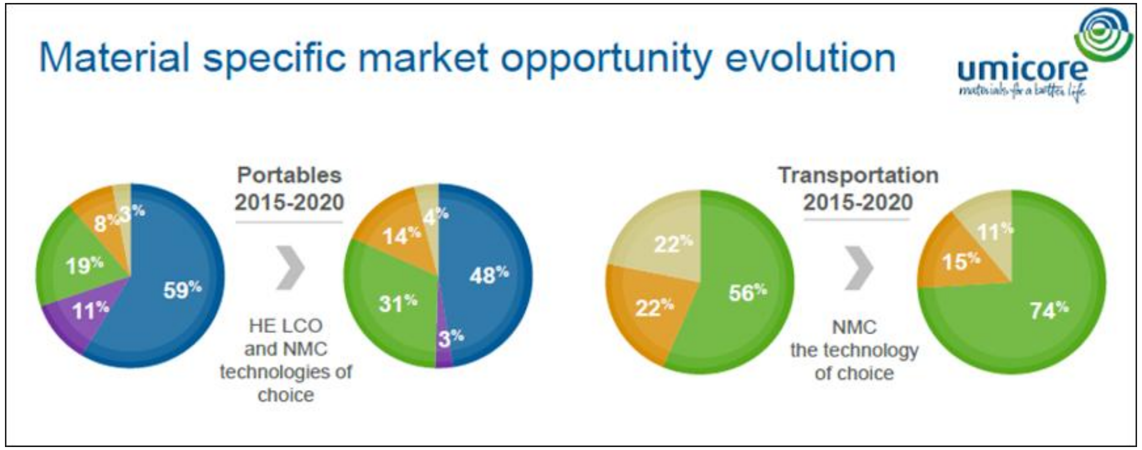


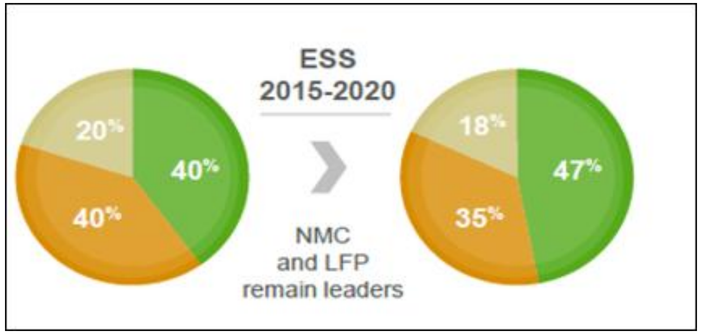
And trends to more polymer types and solid state batteries

- For improved safety



Materials market trends 2015-2020





- ESS evolves to NMC and LFP

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5. Battery systems beyond Li-ion: focus > 400 Wh/kg, > 1000 Wh/l

- Na -ion and Al-ion
- Metal-Air and sulphur based batteries
- Flow batteries
- .....

Other Metal-Ion systems: Na-ion, Al-ion

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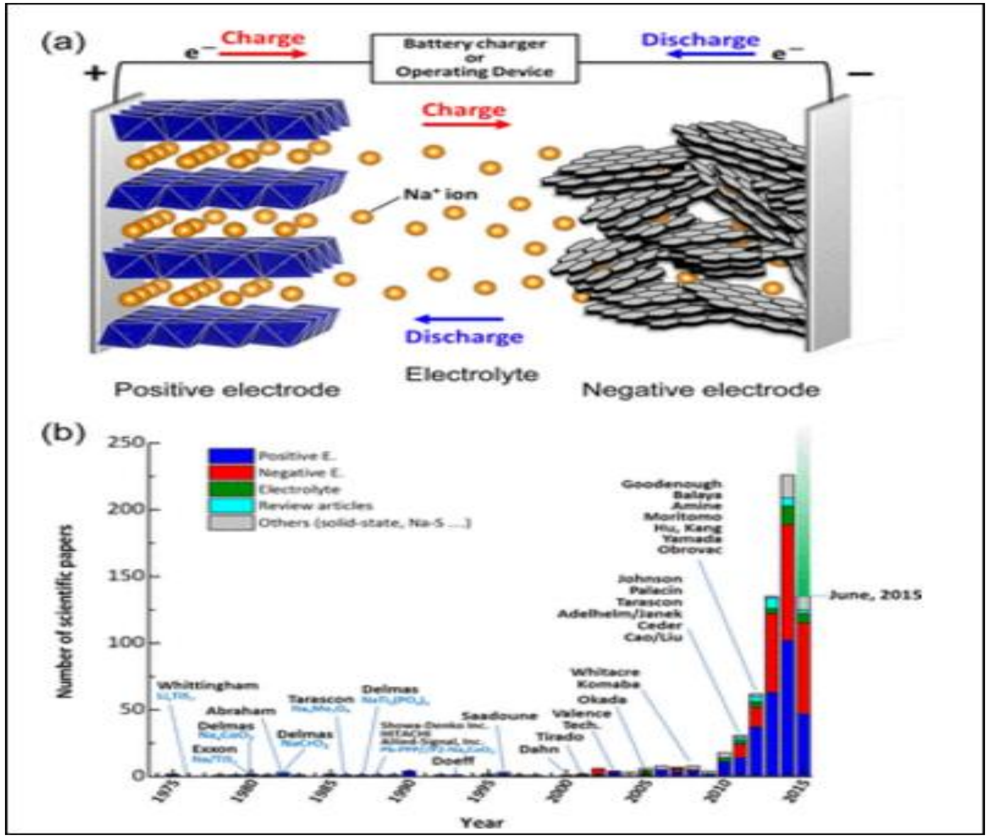
www.alionproject.eu

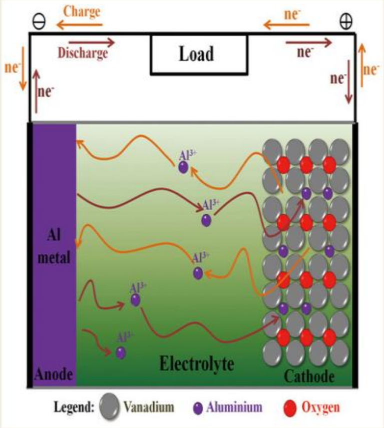
www.naiadesproject.eu



Al-Ion

Stanford Report, April 6, 2015 **Aluminum battery from Stanford offers safe alternative to conventional batteries**

www.nature.com



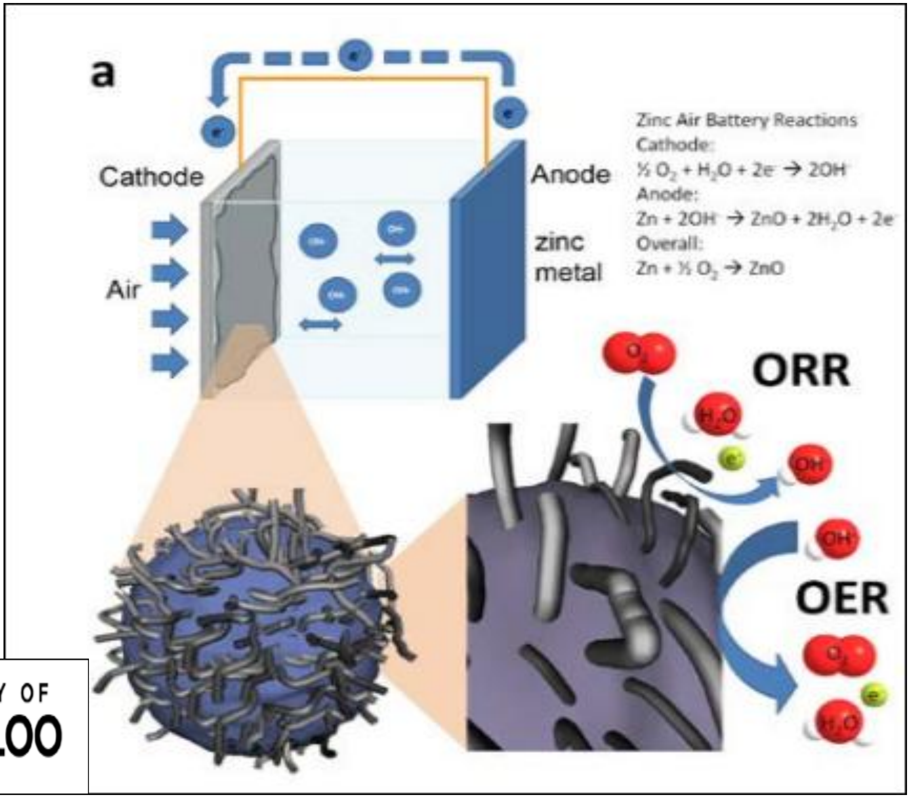
Review—Practical Issues and Future Perspective for Na-Ion Batteries

Kei Kubota[a,b] and Shinichi Komaba[a,b,*,z]

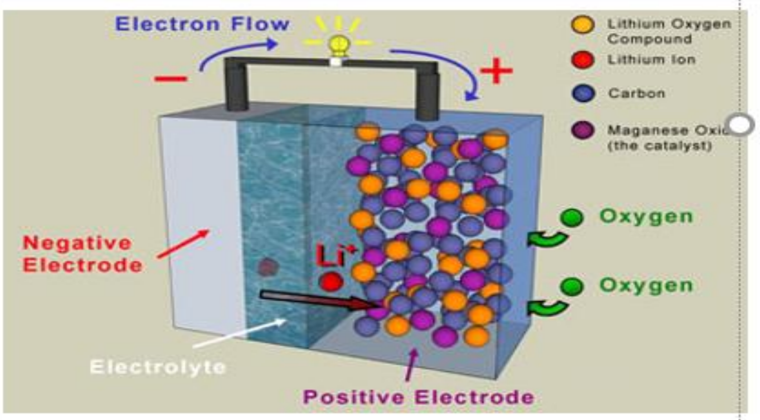
Metal (Zn,Li) - Air

Issues: dendrites,rechargeability,bi-functional air catalysts,electrolyte choice...

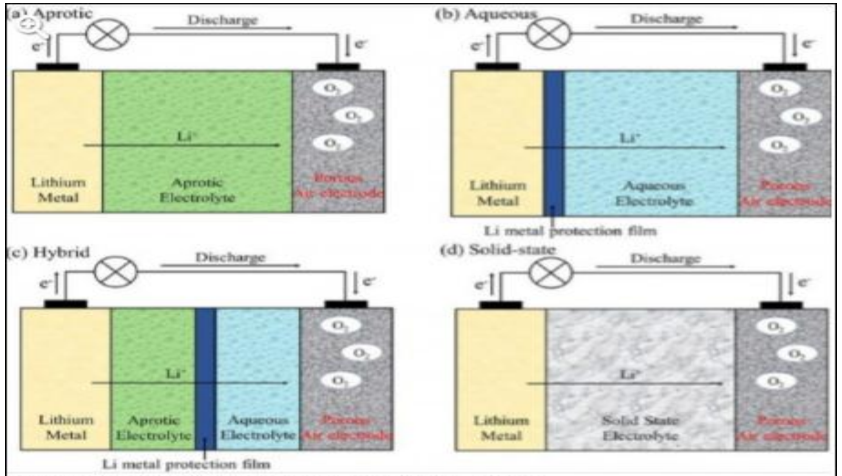
sintef.no/**zas**



UNIVERSITY OF WATERLOO



Univ. St. Andrews (P. Bruce)

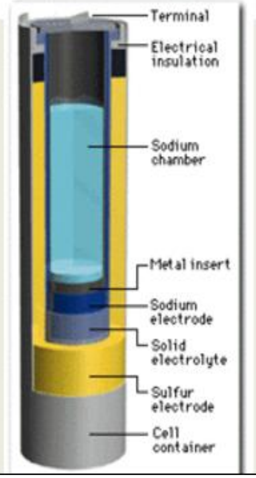


ithium-air battery chemistries (Image: Lu et al, ACS Chemical Reviews)

Na-S /high t° (NGK)

- 2 Na + 4 S → Na_2S_4 E_{cell} ~ 2 V
- **High temperature 300°C**
- Lifetime guaranteed: 15 years
- **Over 300 MW installed**

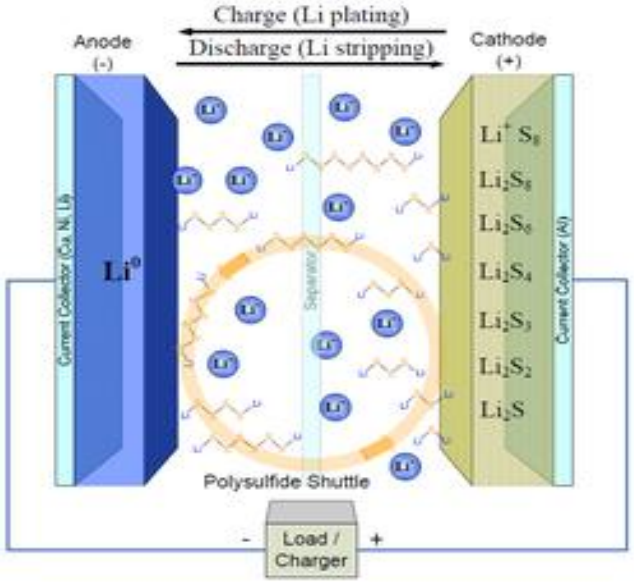
34 MW NAS alongside 51 MW Wind Farm



Li-S / ambient t°

www.aliseproject.com

www.helis-project.eu



www.greencarcongress.com

Sion Power Corporation

Redox Flow

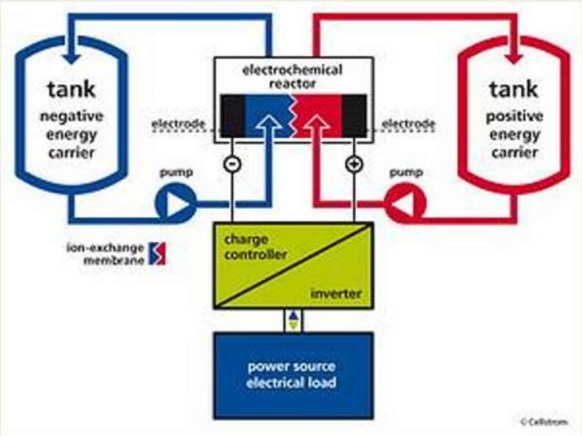
EU projects **GLOBE** (all organic), **InFluENCE** (Semi-Solid Flow Batteries)...

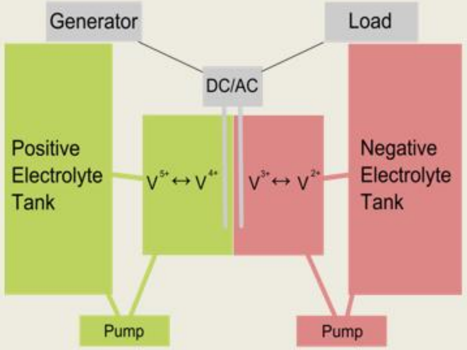
Type of rechargeable flow battery that employs **vanadium redox couples in both half-cells.**

The two electrolytes are separated by a **proton exchange membrane**

Energy/weight	10–20 Wh /kg
Charge/discharge efficiency	75-80%
Time durability	10–20 years
Cycle durability	>10,000 cycles
Nominal cell voltage	1.15–1.55 V

Other flow batteries: Zn-Br2





Maturity curve

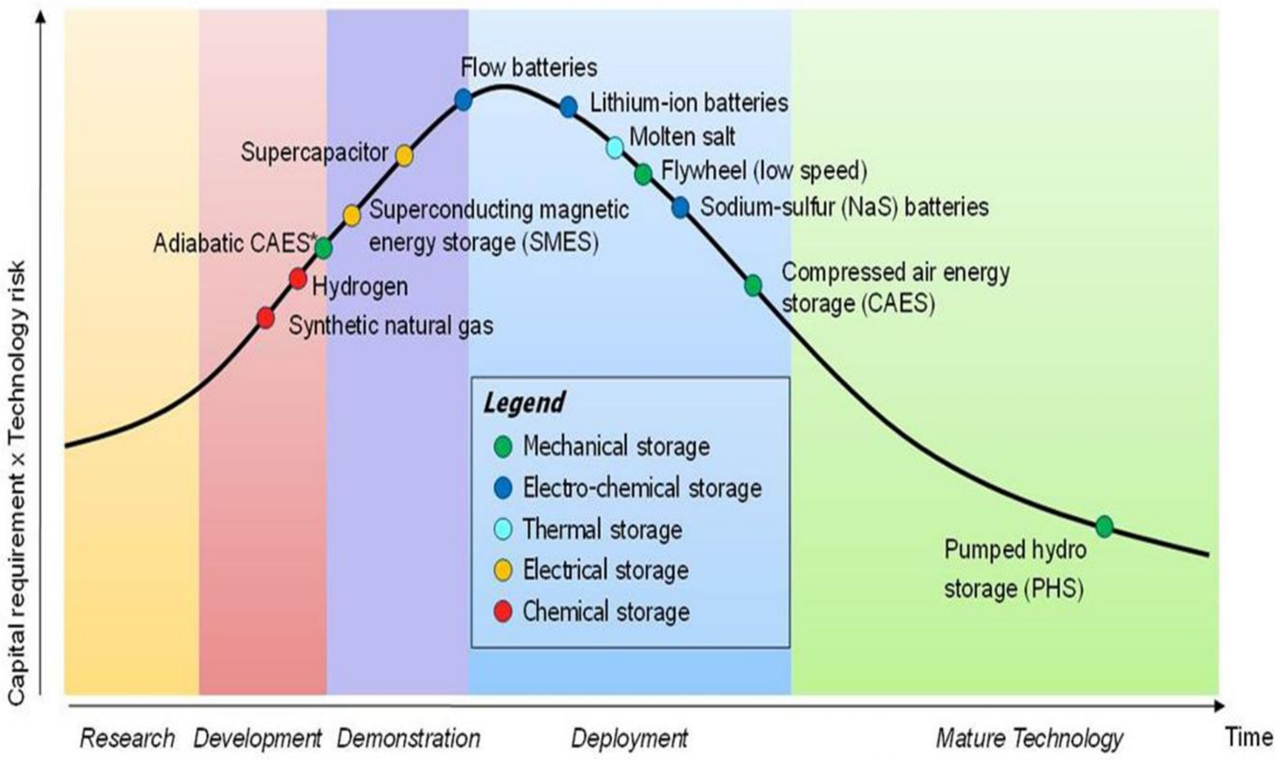


Figure 2: Storage technologies along the maturity curve (SBC Energy Institute, 2013)

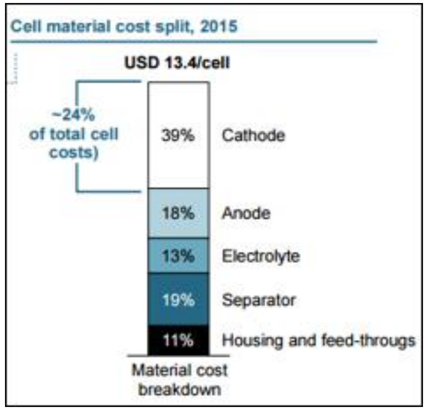
SBC 2013, Kousksou et al. 2014

6. Printed batteries

IoT, MEMS, CMOS memories, Medical implantable	Smart cards, Skin patch, RFID	Wearables, E-textile, Medical device	Smartphone, Tablet, Power tool, Toy	Transport	Large-scale energy storage
Capacity range →					
1 mAh	10 mAh	100 mAh	1 Ah	100 Ah	> 1 kAh
Important features					
• Rechargeable • Small footprint, many micro-batteries • Long life time • Rapid discharge • Tend to incorporate with energy harvesting	• Can be both disposable and rechargeable • Laminar and thin, some with special form factor • Relatively low power • Cost sensitive	• High energy density for small volume • Long working hours • Flexible, stretchable or thin, some with special form factor	• Light-weight and small volume • Long working hours • Some with special form factors • High power	• Safe • Reliable • High power • High capacity	• Cost advantage • Long life time • Reliable • High capacity
					
Technology Status					
Small volume production	Available, mostly customized	Prototypes available	Research to prototype	Research	Very early stage

Source: IDTechEx

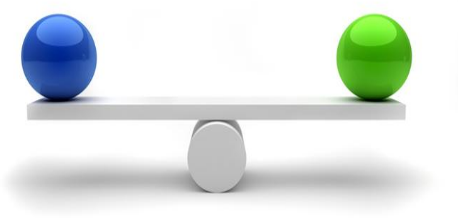
7. Cost perspectives Li Ion



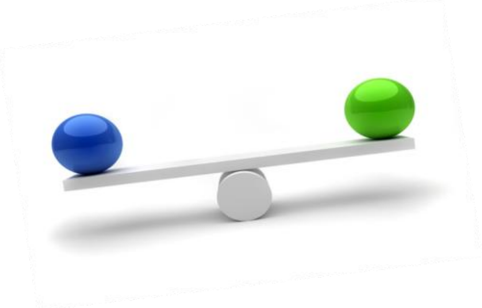
R.Berger

- Cathode Material = Key cost / performance driver

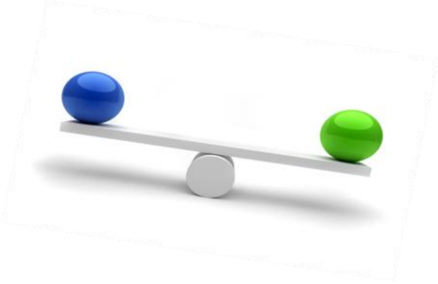
By 2020, the cost in € /kWh has to come down to < 200 €/kWh
For stationary applications down to **< 0,05 €/kWh/cycle**



Price: $/kg
- Cheaper Metal base
- Economies of scale
- Increased yield



Performance: kg/kWh
- Higher Energy density
- Higher Voltage
- "Intelligent design"



Thank you for your attention