An Ultrafast Rechargeable Aluminum-Graphene Foam Battery

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ITRI: innovation-driven

Total Staff: 5,831

Ph.D.：	1,388
Master：	3,243
Bachelor：	1,200
Alumni：	23,745

Total Patents

24,188

Startups & Spinoffs(2015)

240

Industry Services(2015)

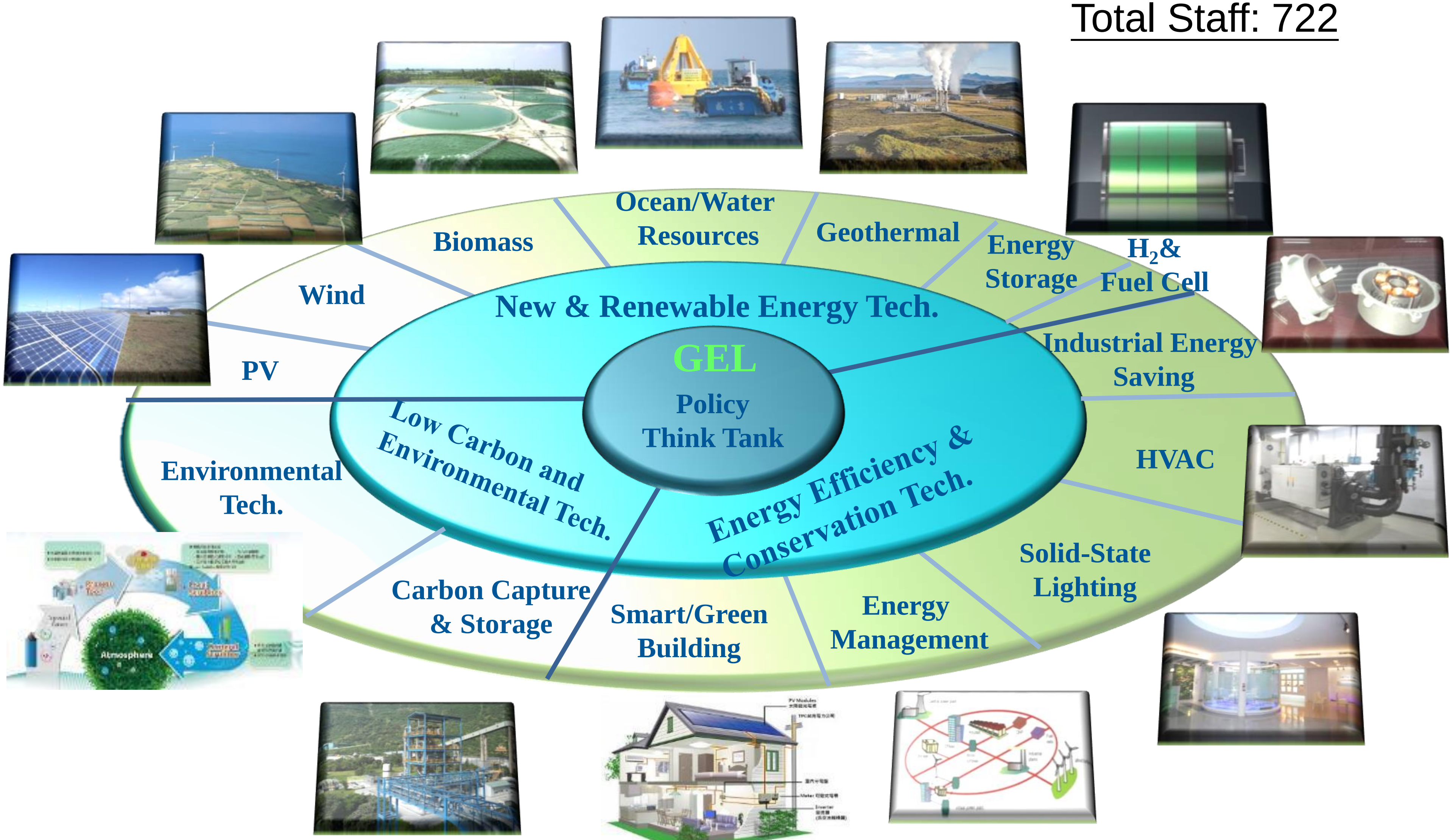
Provided Services：18,351

Transferred Technologies：642

2016.03.01

Green Energy and Environment Research Laboratories (GEL)

Total Staff: 722



2016.08.01

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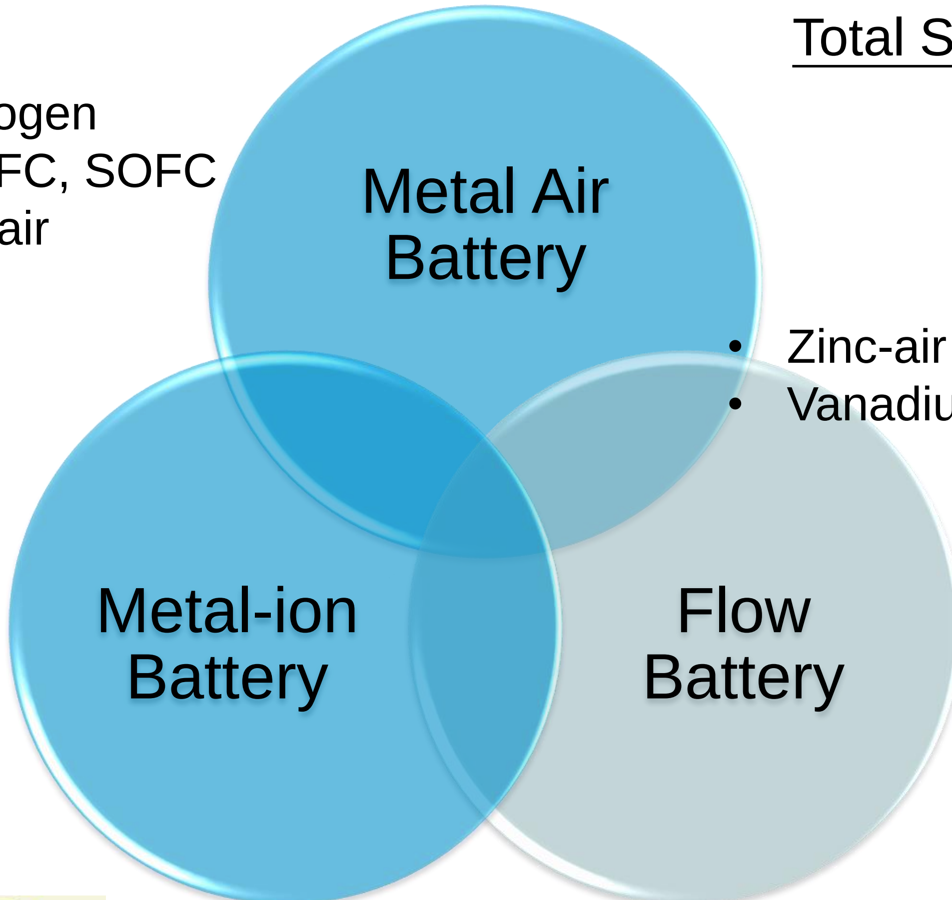
Energy Storage: Open Innovation System Platform

Total Staff: 56

- Hydrogen
- PEMFC, SOFC
- Zinc-air



- Zinc-air Flow
- Vanadium Flow

- Aluminum-ion
- Sodium-ion

中央大學

中正大學

聯合大學

清華大學

東海大學

AsahiKASEI
ASAHI KASEI E-MATERIALS

Stanford

UC Berkeley

BERKELEY LAB
Lawrence Berkeley National Laboratory

中油綠能所

台電綜合研究所

CSC Group
中鋼集團

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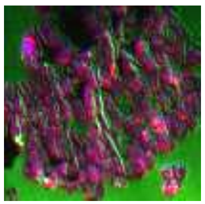
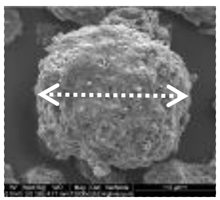
Battery : From Material to Prototyping

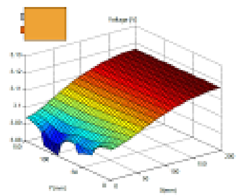
- Anode / Cathode synthesis
- micro-structure Design
- High V electrolyte
- Capacity control





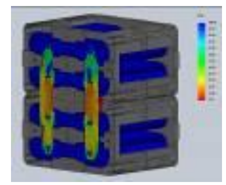
Material Development

- Paste control
- Thermal/Electrical Design/ simulation
- Safety control
- sealing



Cell Design

- Thermal /Electrical conduction
- Mechanical design/simulation
- SOC Information
- Cell Equalization
- Protection



Battery Module Design

Cell Fab.

Recipe of Material System
Electrode and Jelly Roll
Conducting Mechanism
Mathematical Model and Simulation

Performance Test

Capacity and Energy Density
Specific Power
High Current Capability
Cycle Life and Storage/Shelf Life
Impedance Analysis
Failure Mechanism

Safety Test

Mechanical Abuse
Electrical Abuse
Abnormal Environment
Failure Mode Analysis

Module Test

Performance
Safety
Verification

ESS

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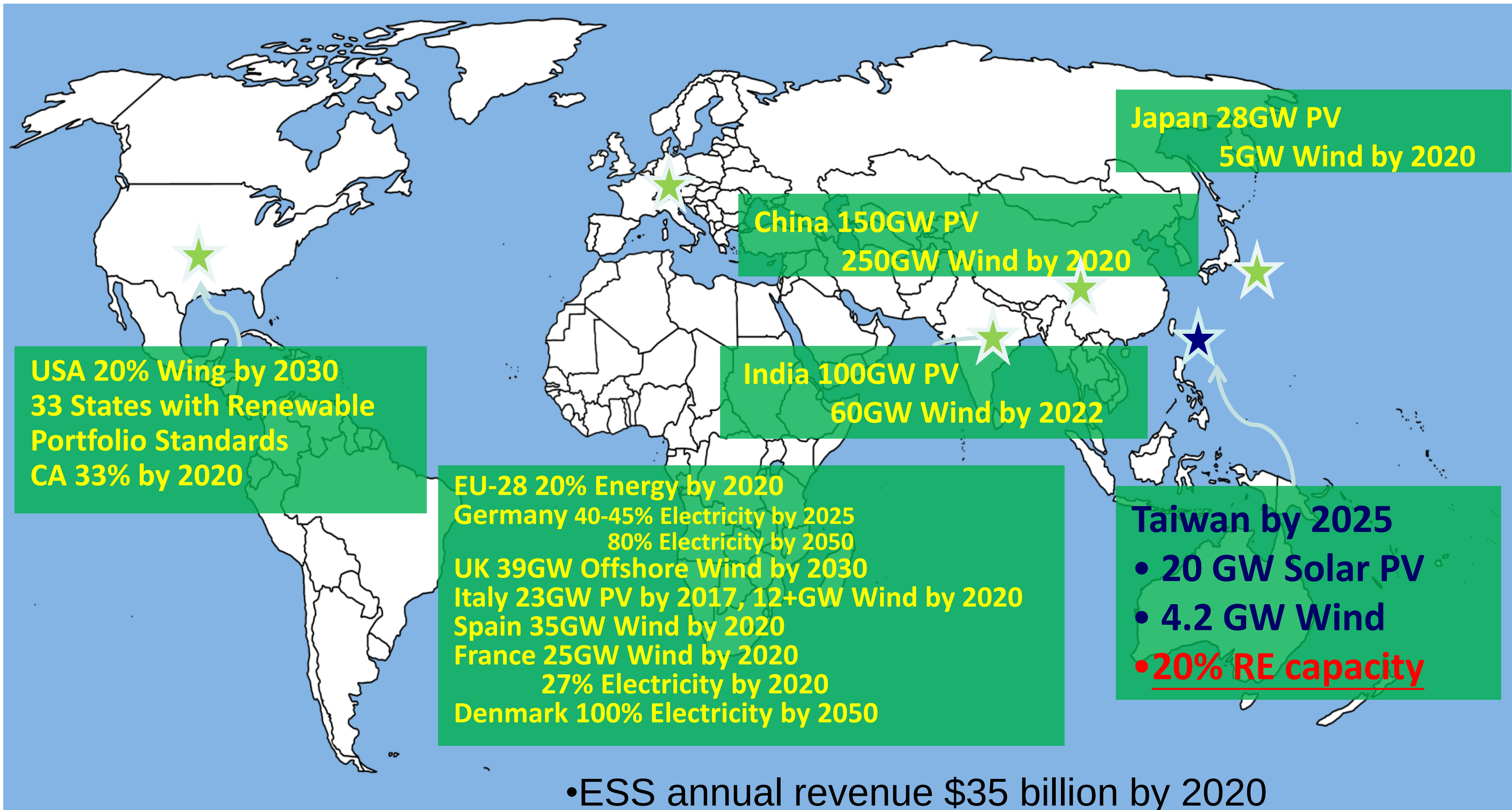
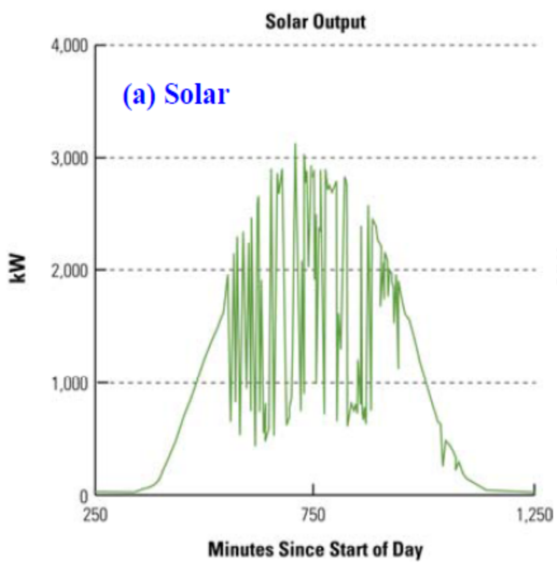
Why Storage ?

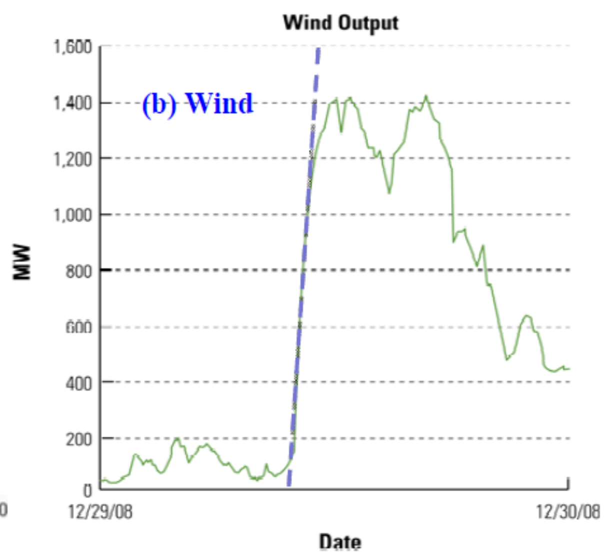
- National energy security for massive renewable energy
- Enabling technology to improve intermittent power quality

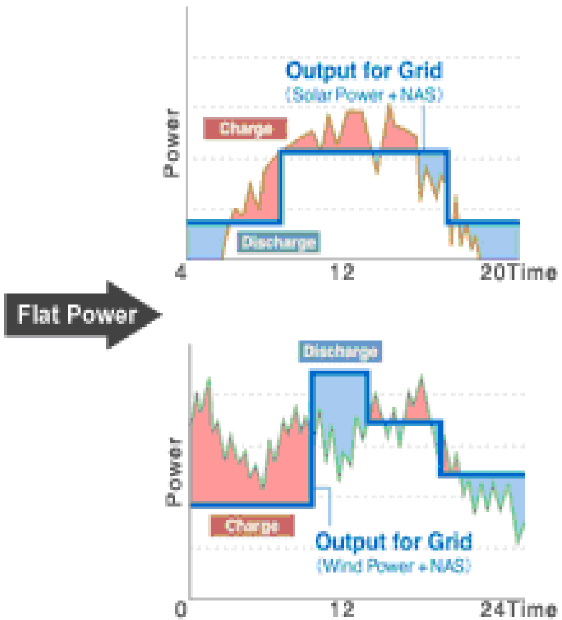


Intermittent Power Improvement

Type I ：Intermittent solar and ramping wind power quality
Storage timing scales: frequency (< 1 sec.), voltage (< 1 min.), power (~min.) and energy (~hours)







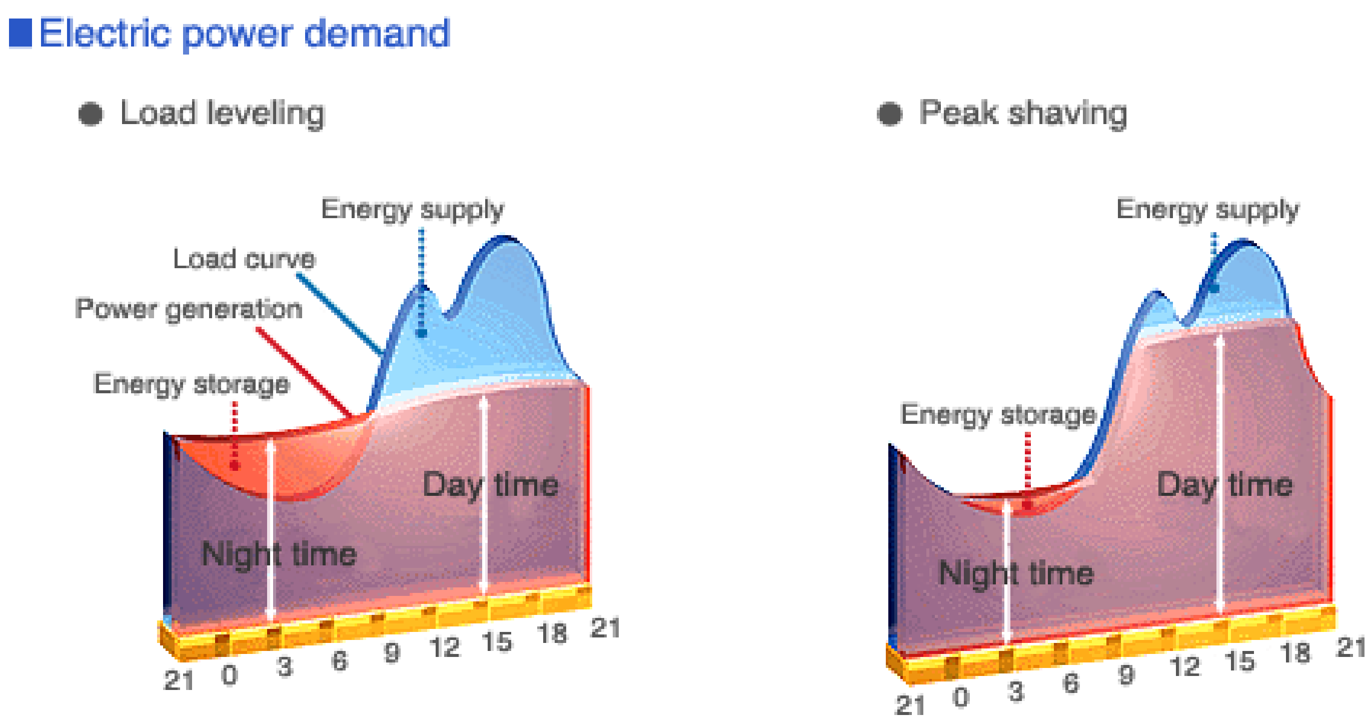
Intermittency of solar generation

The rate of change for power (‘ramp’) ～ MW/min

Source: US DOE ARPA-E (2011), Japan NGK

Diurnal Load Shifting

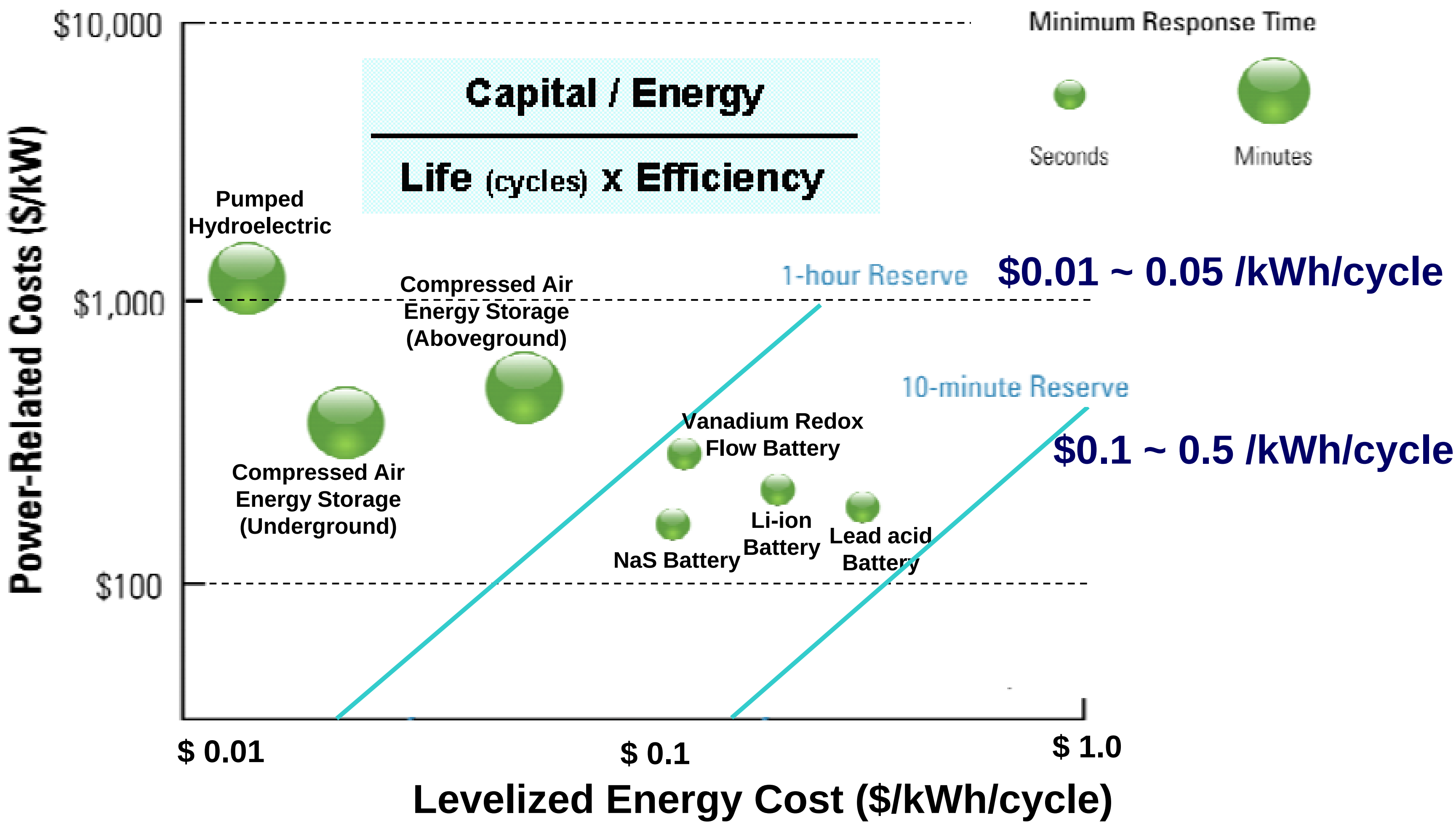
Type II：Storage provides electricity when it is needed
Renewable generation and electric vehicle Integration
Grid / Load management and peak demand shaving



Source: US DOE ARPA-E (2011), Japan NGK

Storage Cost Issues

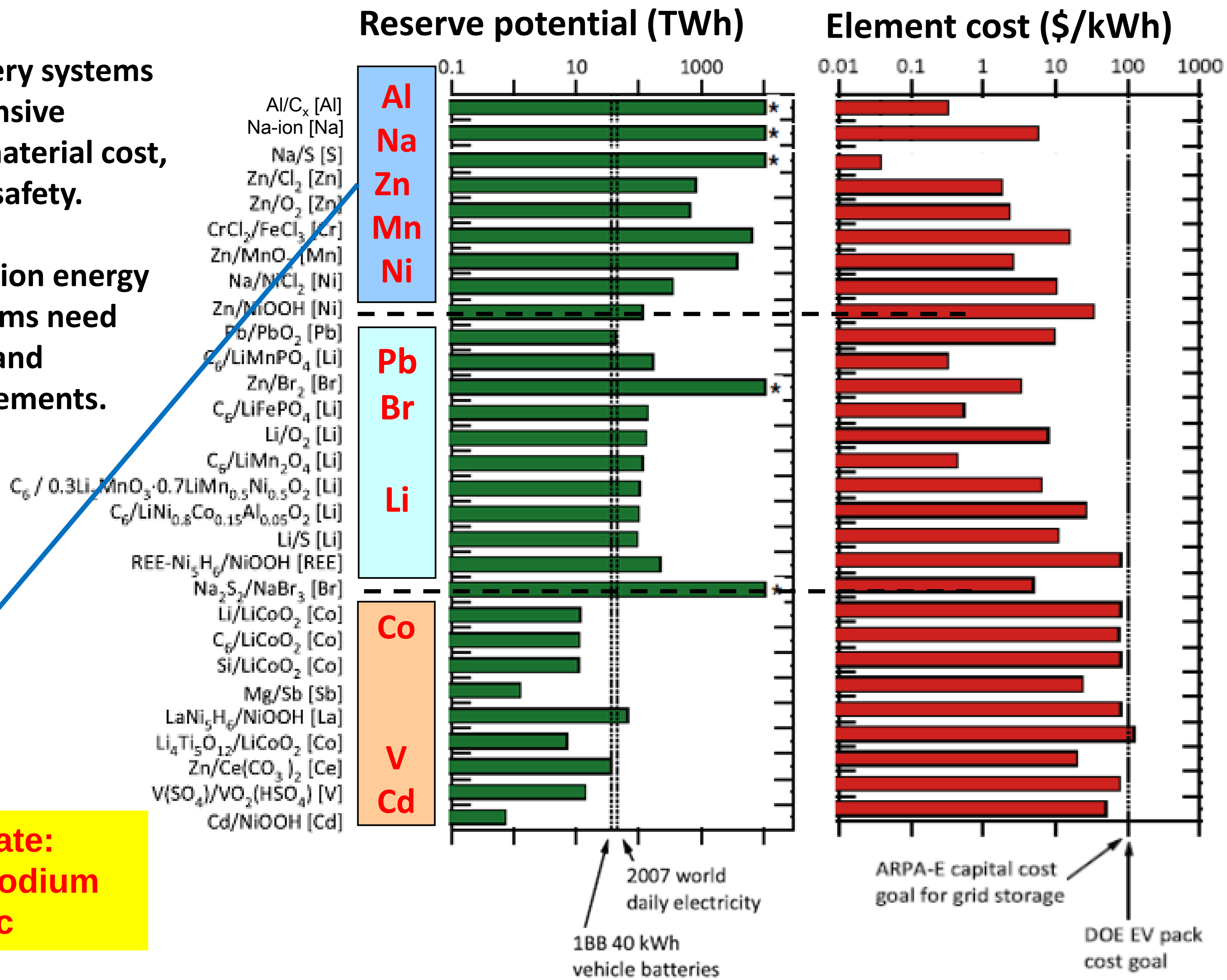
Short-term $0.1 /kWh/cycle → Long-term $0.02 /kWh/cycle



Source: ITRI, 2016; US DOE ARPA-E, 2010

Electrode Metals for Batteries

- Current battery systems are too expensive because of material cost, scarcity and safety.
- Next-generation energy storage systems need **inexpensive** and **abundant** elements.



Al

Na

Zn

ITRI evaluate: Aluminum, Sodium and Zinc

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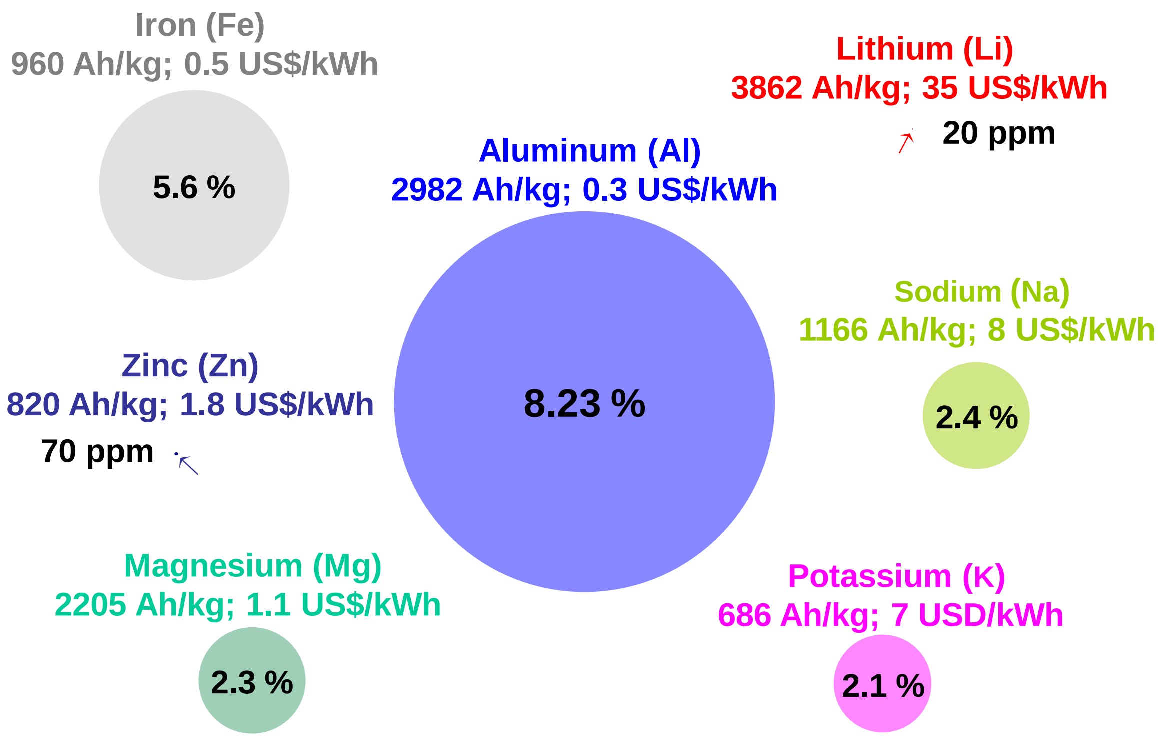
Abundance of Elements in Earth's Crust

- **Electrolytes: stability, hydrogen evolution**
- **Cathode materials: re-chargeability, endured cyclic life**

Abundance of elements in Earth's crust



Al-ion Battery Benchmark

	Voltage (V)	Cyclic Life
Allied Signal	1.7	100
Cornell University	0.6	20
IICT*	1.1-0.2	40
Sandia National Lab.	1.8-0.8	100
ITRI/Stanford	2.0	7,500-10,000

Ref: ITRI, 2016; Journal of The Electrochemical Society, 1988, 135(3): 650-654.; Chemical Communications 2011, 47(47): 12610-12612.; The Journal of Physical Chemistry C, 2014, 118(10): 5203-5215.; Journal of The Electrochemical Society, 2013, 160(10): A1781-A1784. Nature 520 (2015) 325.

*IICT: Indian Institute of Chemical Technology.

Past History of Al Battery

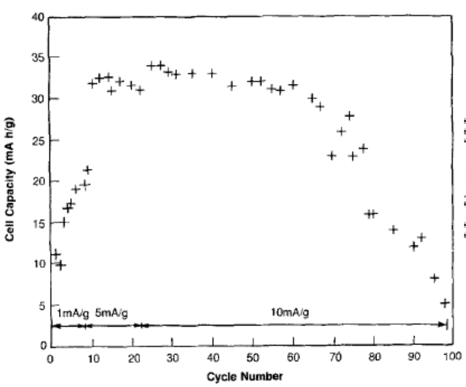
- **Performance of Al battery (1988-2014)**
  - Capacity decay by 100 cycles/Low discharging plateaus (<1.5V)
- **Why people cannot have good Al battery?**
  - Cathode material disintegration: natural graphite[1]

  → Rapid capacity decay (85% over 100 cycles)[4]

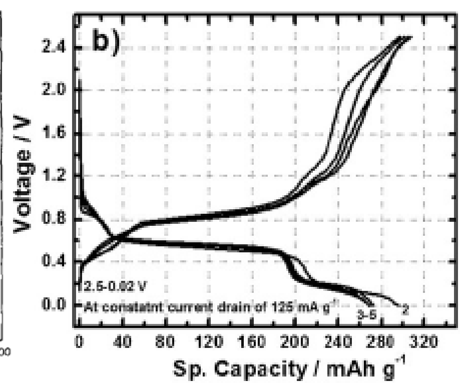
  - Inactive cathode: V_2O_5 (S.S.)[2] or Conducting polymers[3] or Fluorinated Graphite [4]

[1] Chemical Communications 2011, 47(47): 12610-12612.; [2] The Journal of Physical Chemistry C, 2014, 118(10): 5203-5215.; [3] Journal of The Electrochemical Society, 1988, 135(3): 650-654.; [4] Journal of The Electrochemical Society, 2013, 160(10): A1781-A1784.

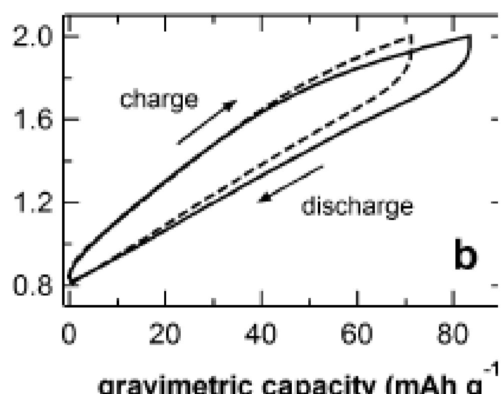
  → Low discharge voltage of 0.6 V[2] or Capacitor behavior[3,4]



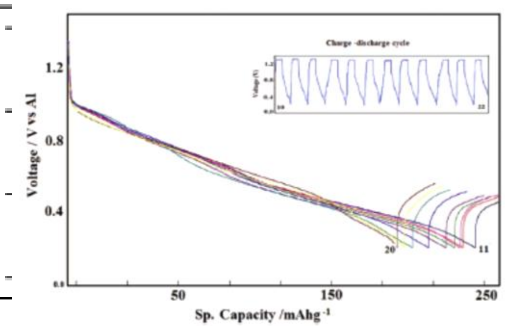
Natural graphite



V_2O_5 nano-wire

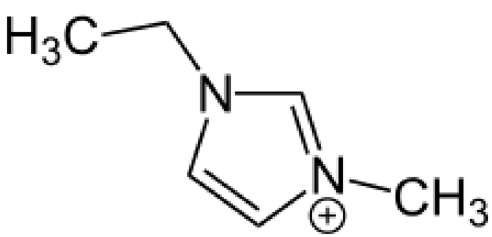


Conducting polymers

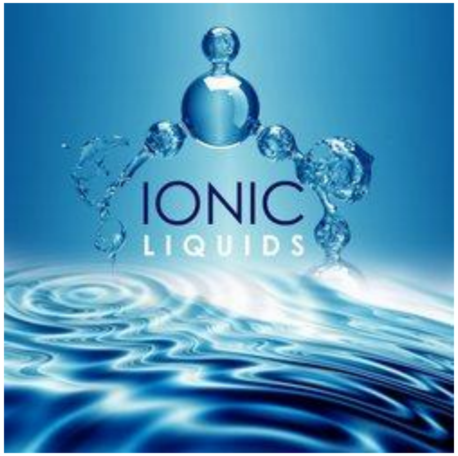


Fluorinated Graphite

Aluminum + Graphite + Salts = Al Ion Battery



Cl^{-} + $AlCl_3$ =

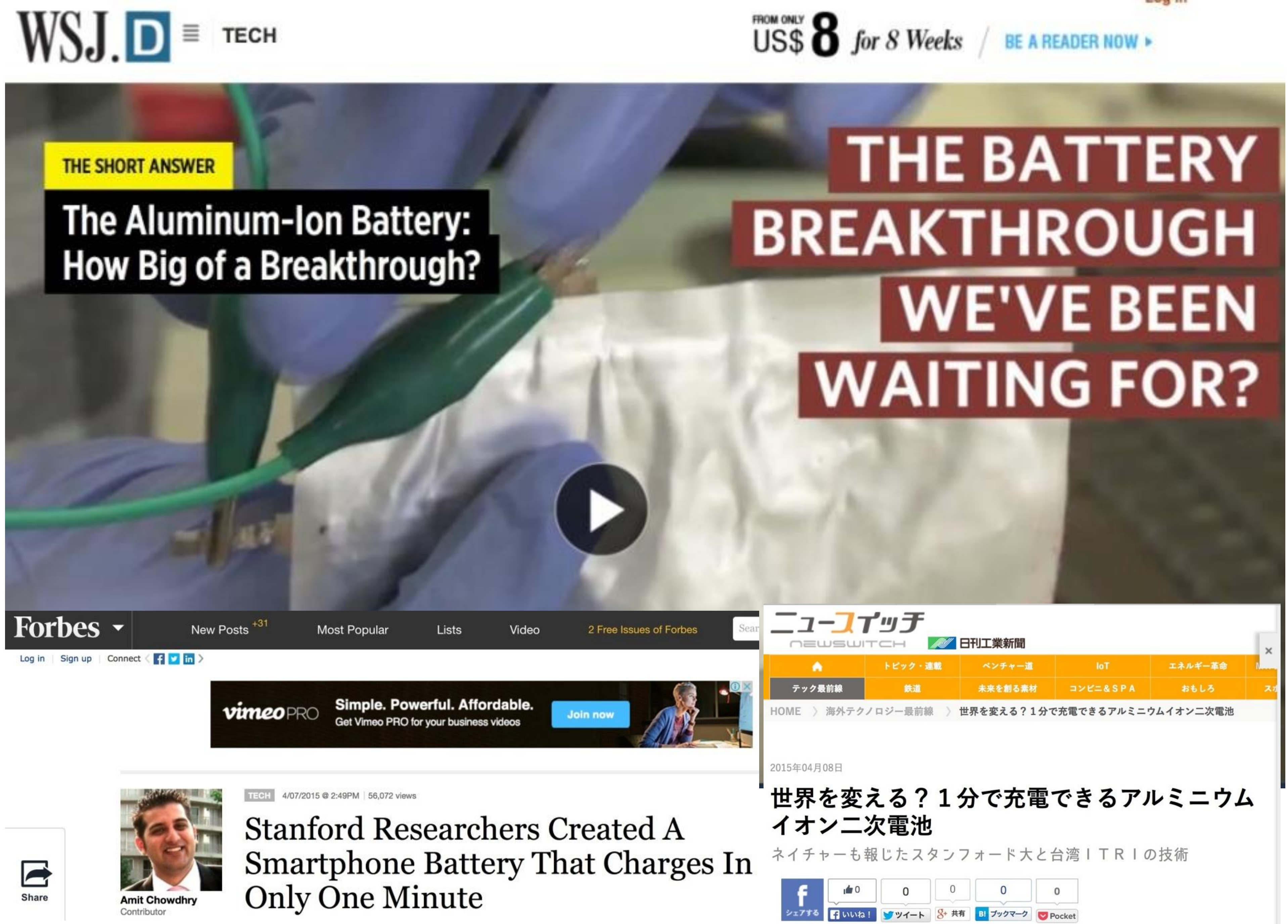


1 : 1.3

Abundant anions in ionic liquid solution:

$AlCl_4^-$ & $Al_2Cl_7^-$

Meng-Chang Lin, Ming Gong, Yingpeng Wu, Bingan Lu, et. al., Nature, 2015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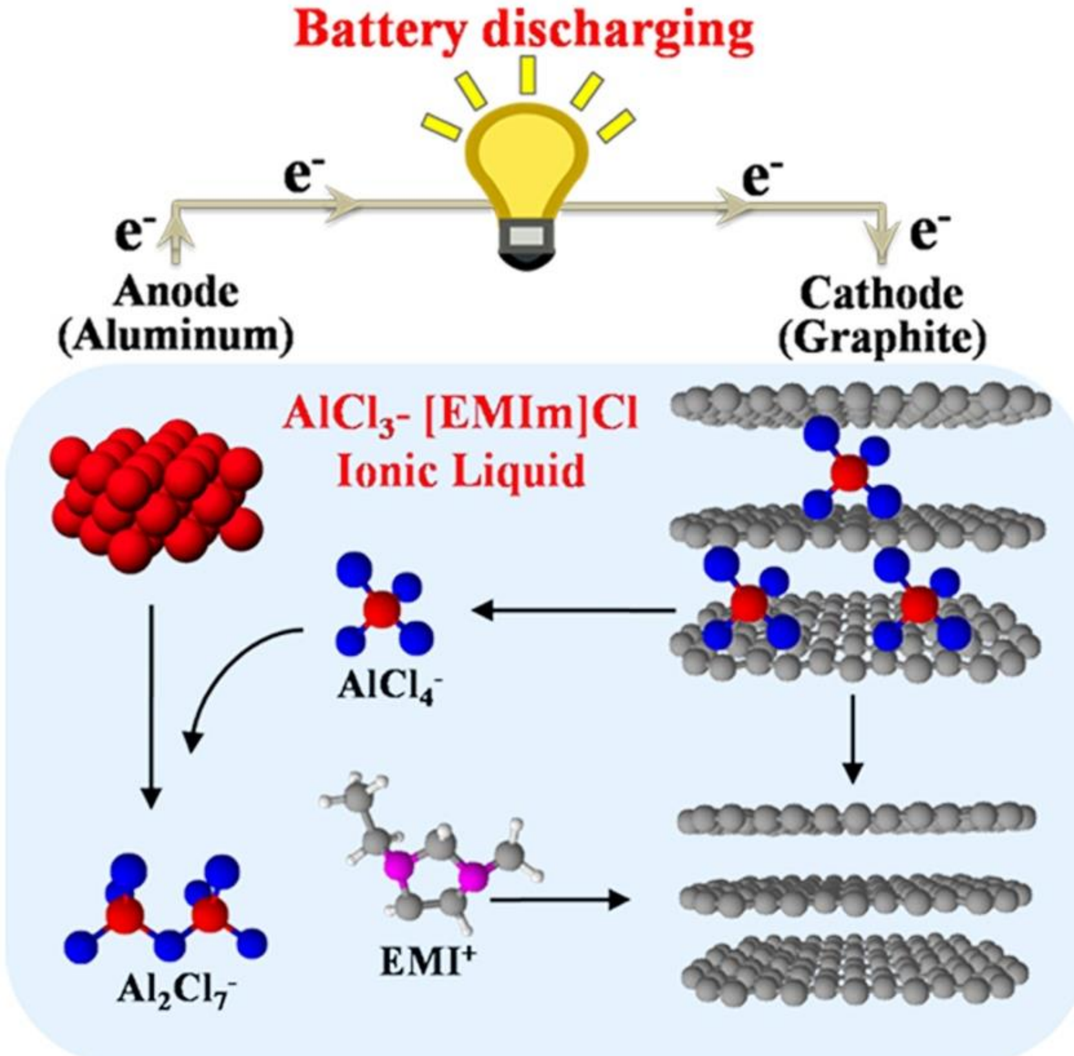
Mechanism of Aluminum Batteries

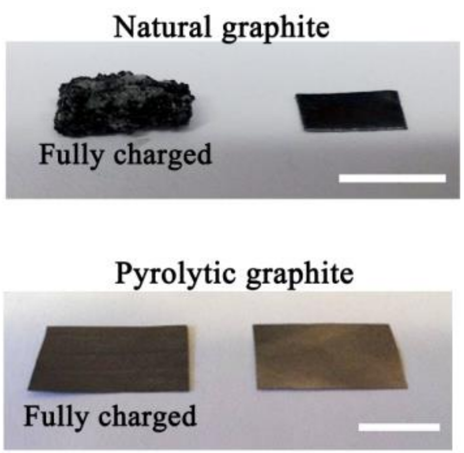


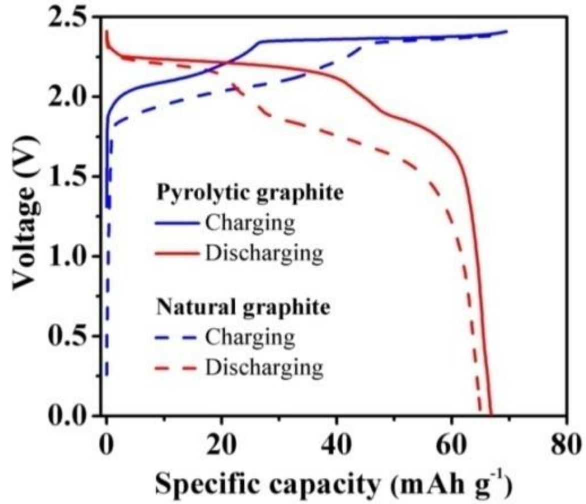
$Al + 7AlCl_4^- \rightarrow$
$4Al_2Cl_7^- + 3e^-$

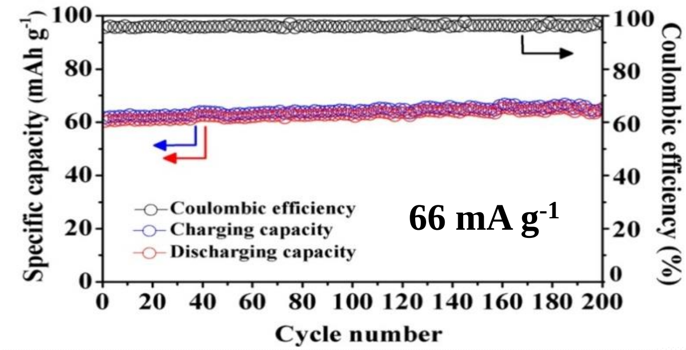
$C_n[AlCl_4] + ze^- \rightarrow$
$zAlCl_4^- + C_n[AlCl_4]_{(1-z}$

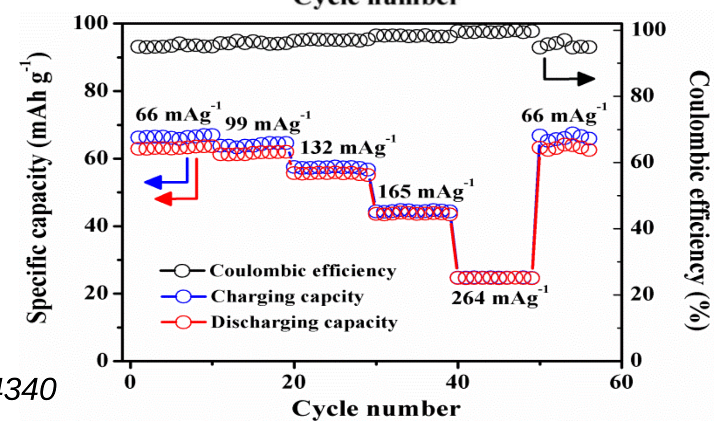
Novel Cathode Material-1

- **Pyrolytic graphite: a novel cathode material**
  - No expansion was observed during cycling
  - High discharging voltage: 2.25-2.0V
  - High cycling stability: >200 cycles and no capacity decay
  - **However, only 2C rate capability (66 mA g^{-1}) was achieved**





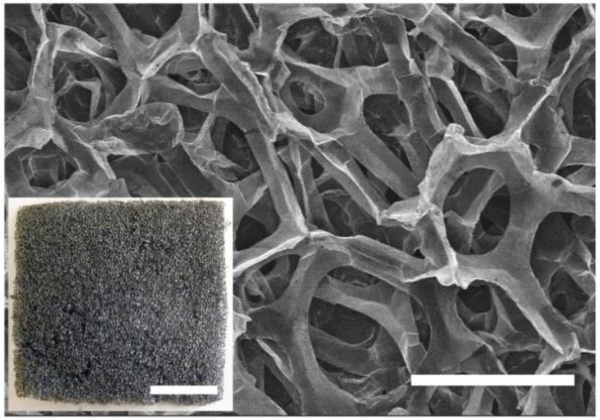




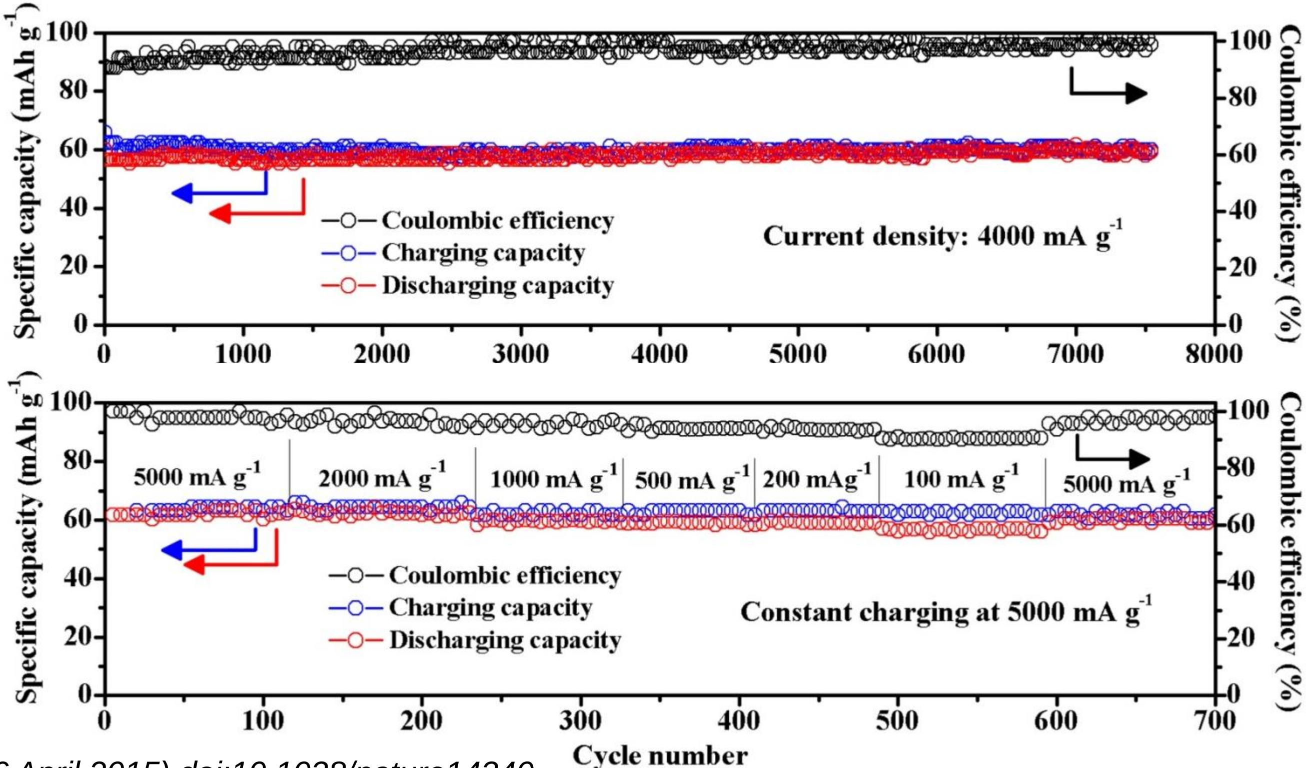
M.-C. Lin et al., Nature 520, 324–328 (16 April 2015) doi:10.1038/nature14340

Novel Cathode Material-2

- **3D graphene foam: a novel cathode material**
  - High discharging voltage: 2.25-2.0V
  - Ultra-fast charge/discharge at 5000 mA/g (3000W/kg [75C])
  - High cycling stability: >7500 cycles and no capacity decay
  - 1 min fast charge and slow discharge



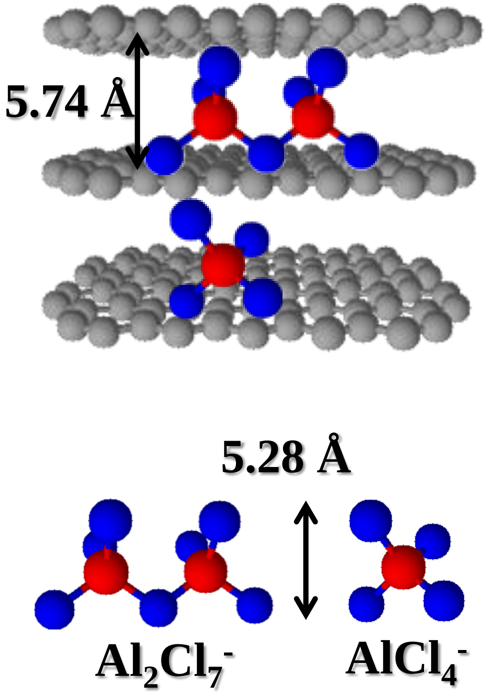
Microstructure of 3D graphene foam

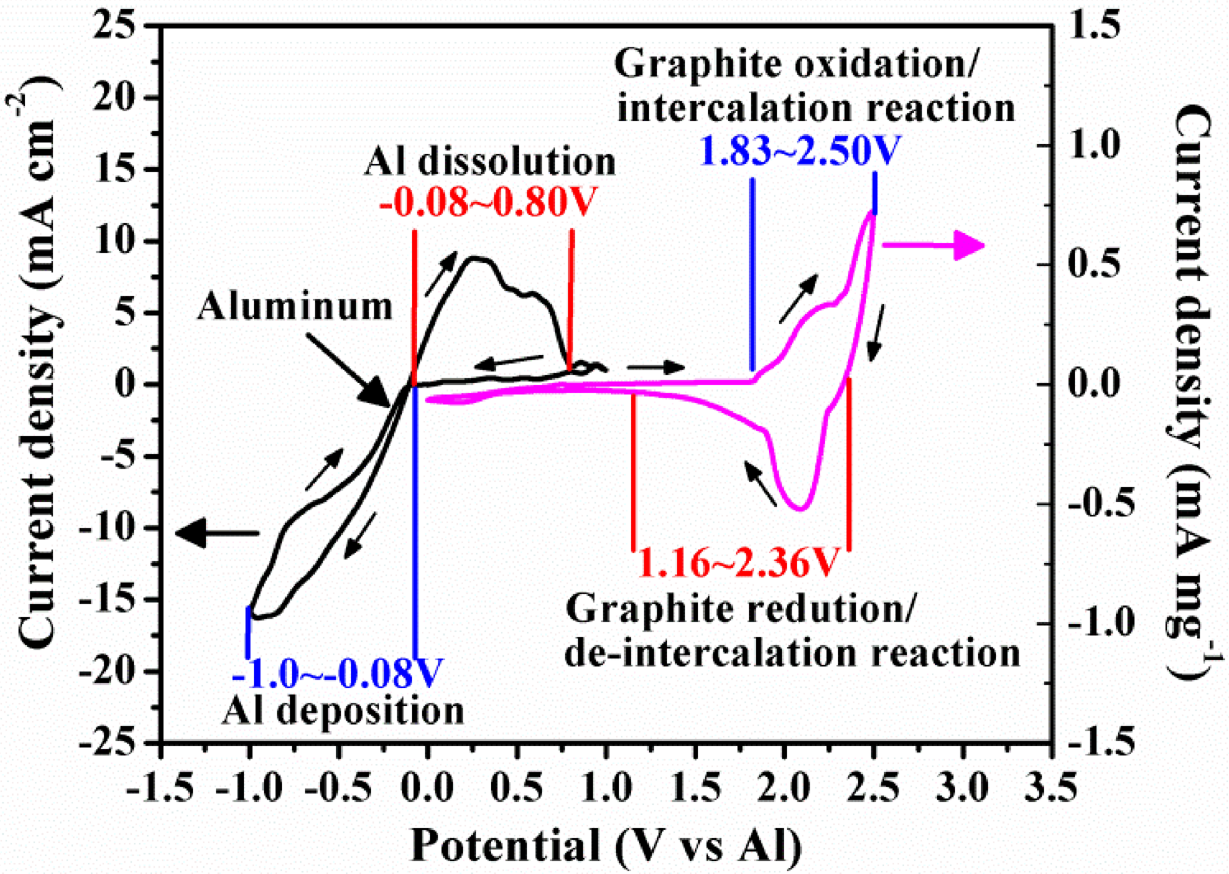


M.-C. Lin et al., Nature 520, 324–328 (16 April 2015) doi:10.1038/nature14340

Charge-Discharge Mechanism

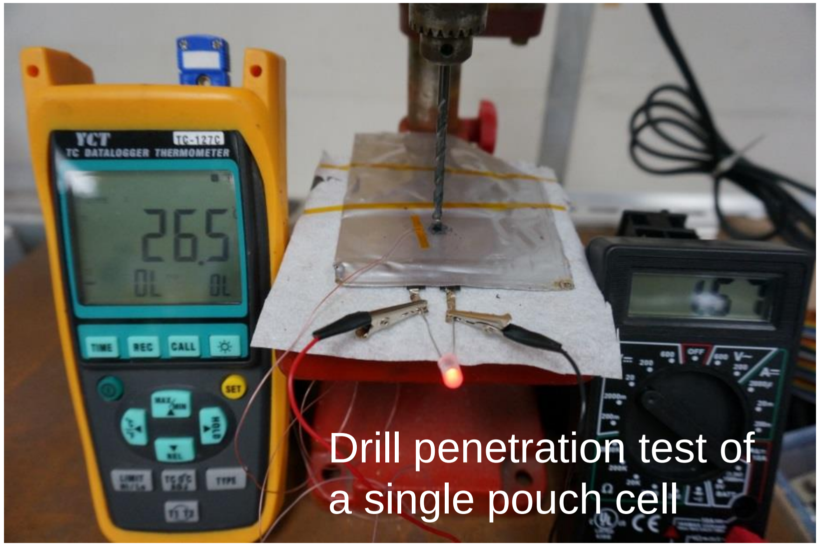
- **Anode: Deposition and dissolution of Al**
  - >99% Coulombic efficiency
- **Cathode: Intercalation and deintercalation reactions**
  - $AlCl_4^-$ and $Al_2Cl_7^-$ anions were involved ?





M.-C. Lin et al., Nature 520, 324–328 (16 April 2015) doi:10.1038/nature14340

Prototyping of Al Battery



Drill penetration test of a single pouch cell

4V/2Ah Al battery with EMS (Energy Management System)

14V/2Ah Al-Battery

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Acknowledgement

- Many thanks to MOEA, ITRI and Stanford University for financial supports and technical discussions.
- Valuable advising: Professor Hongjie Dai

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HORIZON 2020 ALION Project Kick Off Meeting @ LEITAT

June 19, 2015

High Specific Energy Aluminium-ion rechargable decentralised electricity generation sources (ALION)

The overall objective of the ALION project is to develop aluminium-ion battery technology for energy storage application in decentralised electricity generation sources. ALION pursues an integral approach comprising electroactive materials based on "rocking chair" mechanism, robust ionic liquid-based electrolytes as well as novel cell and battery concepts, finally resulting in a technology with much lower cost, improved performance, safety and reliability with respect to current energy storage solutions (e.g. Pumped hydro storage, Compressed air energy storage, Li-ion battery, Redox Flow Battery…).

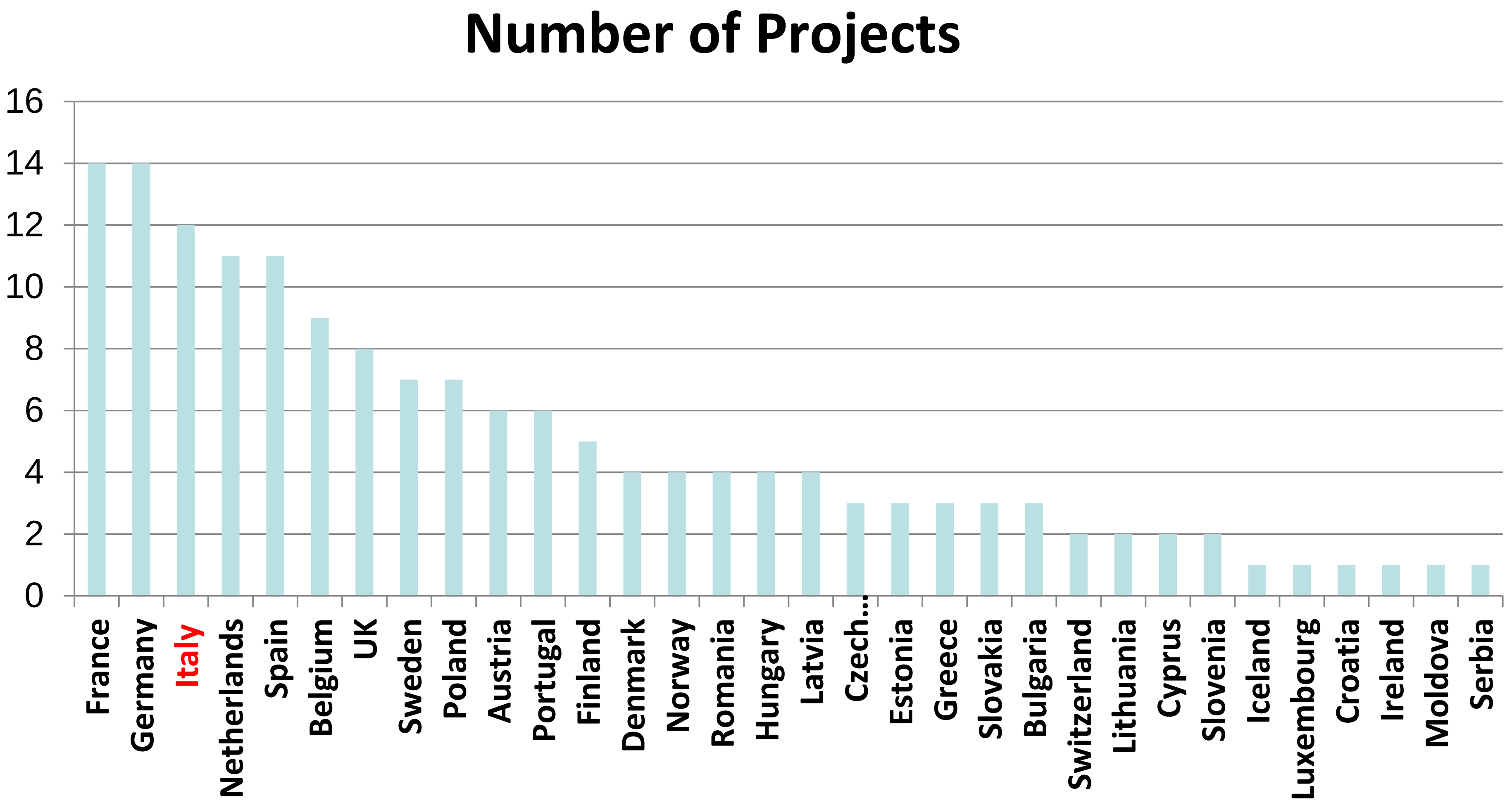
The project covers the whole value chain from materials and component manufacturers, battery assembler, until the technology validation in specific electric microgrid system including renewable energy source (i.e. mini wind turbine, photovoltaic system…). Thus, the final objective of this project is to obtain an Al-ion battery module validated in a relevant environment, with a specific energy of 400 W.h/kg, a voltage of 48V and a cycle life of 3000 cycles.

The Project is funded by European Commission with GA: 646286, led by LEITAT and involves 13 partners from all across Europe.

Why Partner With Taiwan

- Fully eligible to participate in Horizon 2020
- Bring funding from Taiwan
- Contributes unique expertise into the projects
- Access to markets and networks in Asia-Pacific

Taiwan's H2020 Partner Countries



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