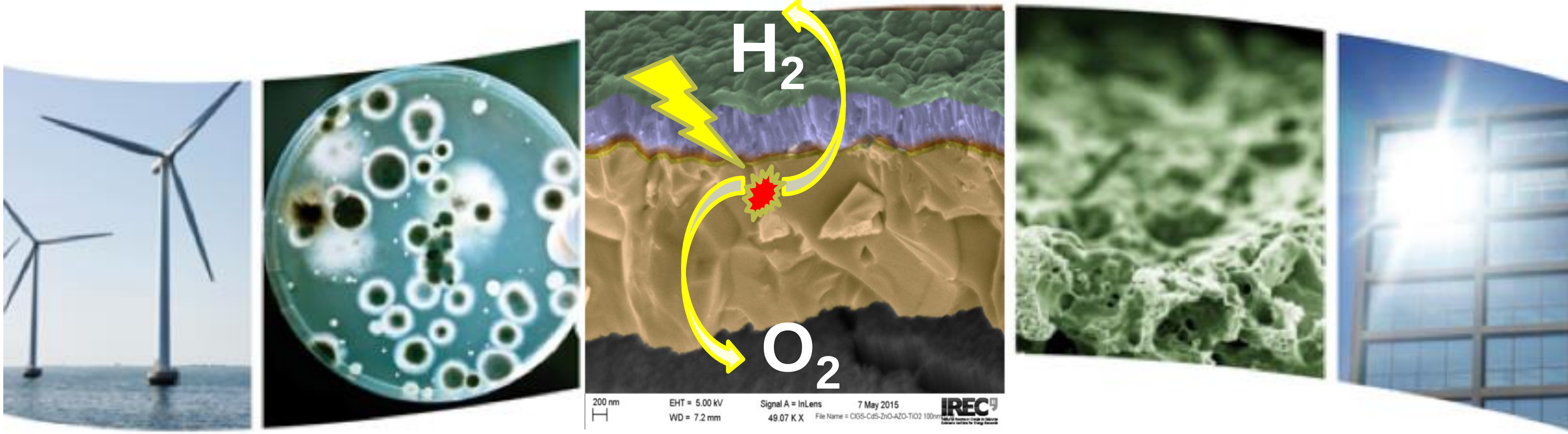

FLOW REDOX BATTERIES

J.R.Morante

IREC, Catalonia Institute for Energy Research, Plaça de les Dones de Negre,1.
Sant Adrià del Besòs, 08930. Spain.
Department of Electronics, University of Barcelona, C/Martí i Franquès,1.
Barcelona,08028. Spain.

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1 ANTECEDENTES

Nowadays, the circular economy of carbon dioxide constitutes one of the major world challenges.

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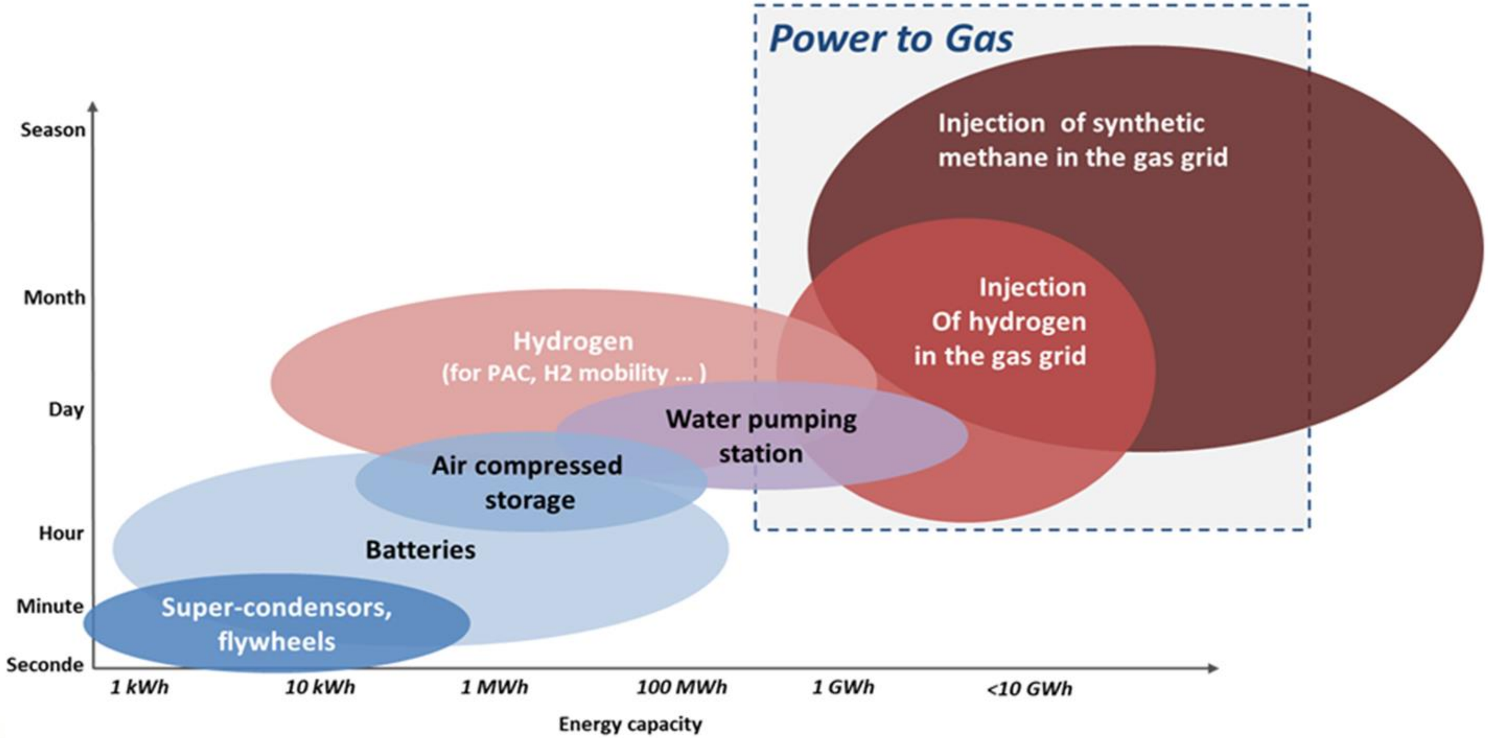
Interest in sustainable and **clean energy sources** such as solar energy, wind and marine energy is growing.
To address the key issue of the intermittency with these energy sources, more **efficient energy storage** and/or conversion systems such as electrical capacitors, **batteries** and conversion of electricity into **high energy-density chemicals** (e.g., hydrogen, fuels) will need to be developed.



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Electrical grid

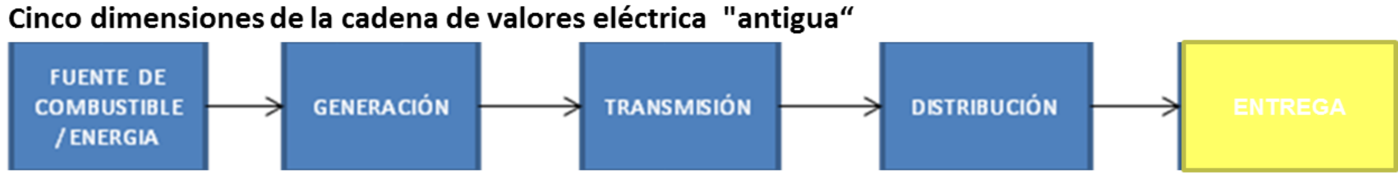
- One direction from generation to end user
- Multidirectional.
- Smart grid:
  - New actors: **Storage**
  - New figures: Aggregators

Energy generation:

- Centralized
- Distributed

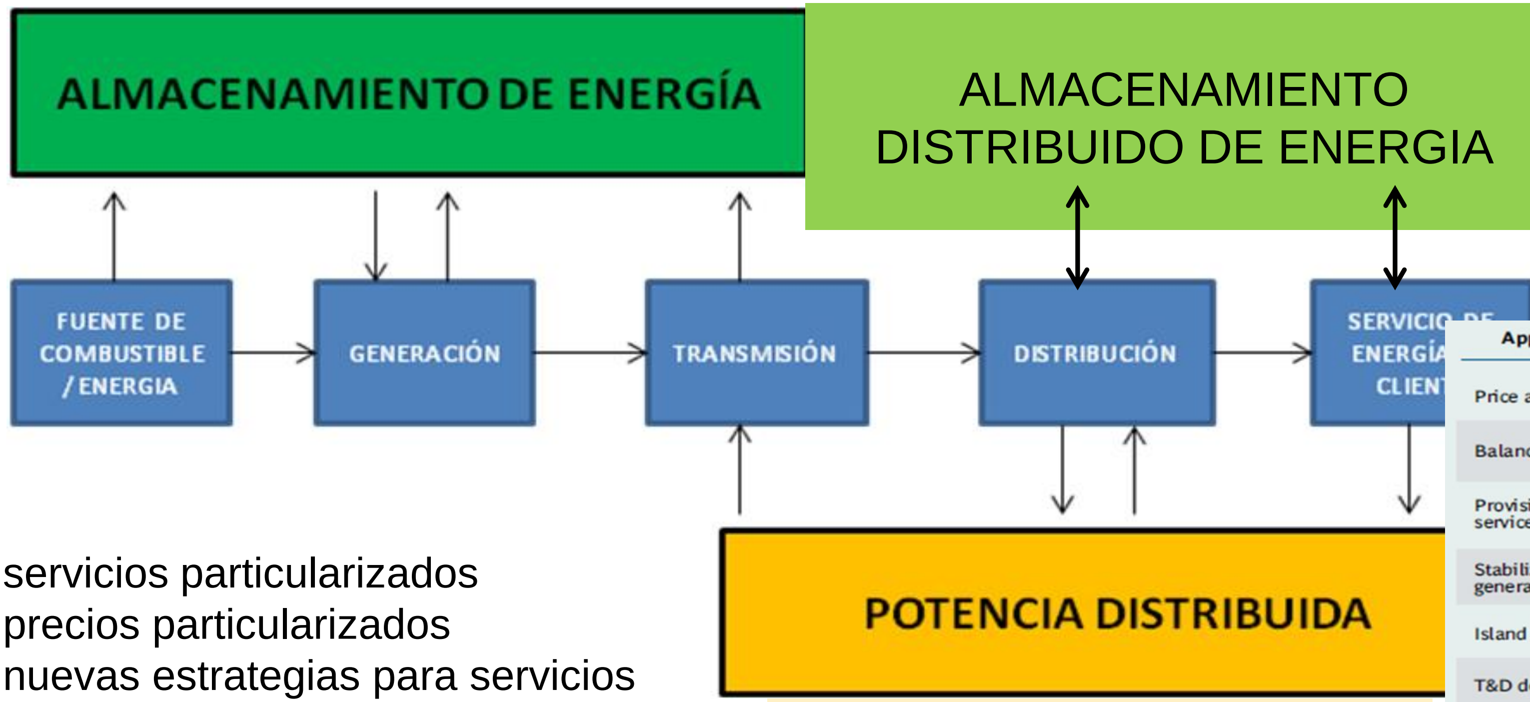
Energy storage

- Centralized
- Distributed



Camino tradicional: Servicio regulado con funciones incluidas

Nueva cadena de valores eléctricos con almacenamiento de energía con una "sexta dimensión"



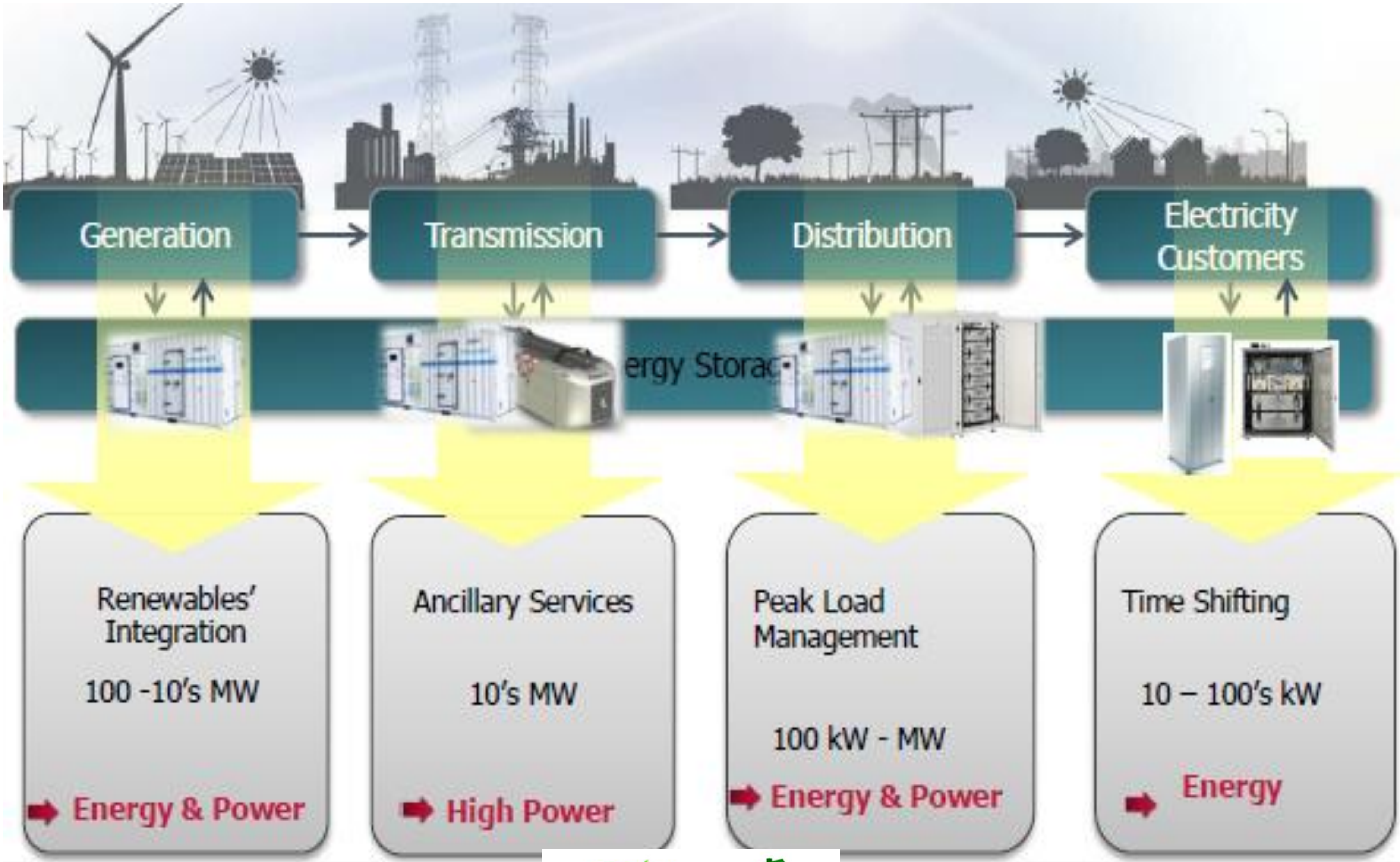
ALMACENAMIENTO DISTRIBUIDO DE ENERGIA

- servicios particularizados
- precios particularizados
- nuevas estrategias para servicios
- servicios privatizados

INTEGRACION DE ENERGIA RENOVABABLES

Gastos de generación de la energía: variable dependiendo del consumo

Gastos de transporte y distribución: fijos a repartir



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Requirements for Energy Storage Systems

- Dynamic Cycling
  - Changing power / energy patterns
  - At variable DOD
- High Power capability
- Immediate response
- SOC management
  - Operation at variable, unpredictable SOC
  - Accurate, real-time SOC indication is a must
- Excellent energy efficiency
- Good calendar and cycle life
- Symmetric Charge and Discharge Power
- Compact –transportable

"I want ..."

Long Life

Powerful system

Reliable Operation

High Availability

Long guarantees

Low TCO

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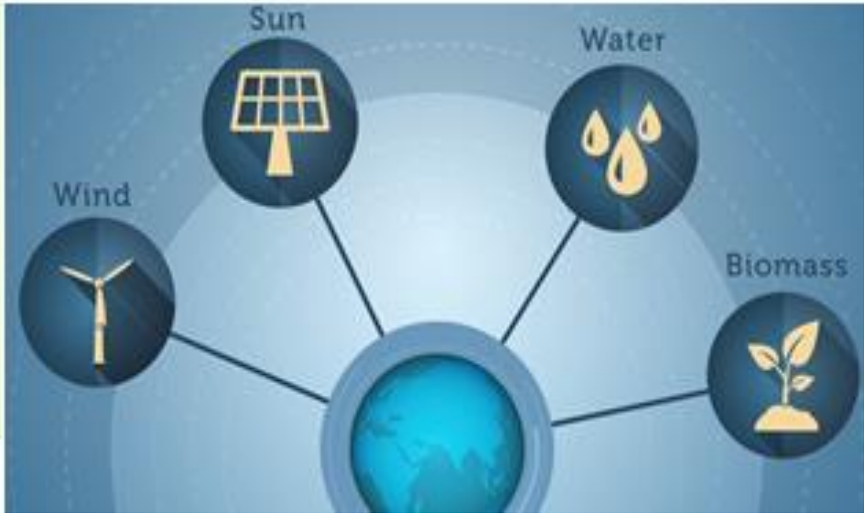
TCO=total cost owner


Sistemas de generación
Sistemas de almacenamiento de energía
Operador del sistema eléctrico
Consumidores


Sun
Water
Wind
Biomass

ACCESO A ENERGIA SOSTENIBLE BARATA Y ABUNDANTE

disponibilidad de redes fuertes frente o débiles:

grandes centrales frente generación distribuida.

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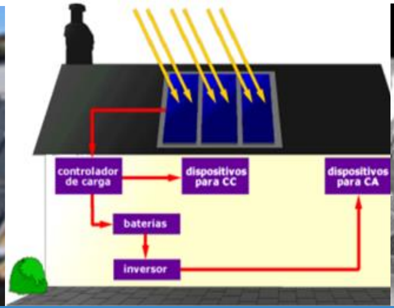
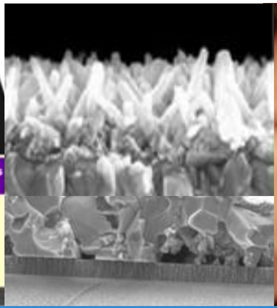
FAVORECER / EXTENDER EL USO DE ENERGIA RENOVABLE

intermitencia y sobreproducción

eficiencia económica (costes) y solidaridad social (tasas)



disponibilidad de redes fuertes frente o débiles:

grandes centrales frente generación distribuida.

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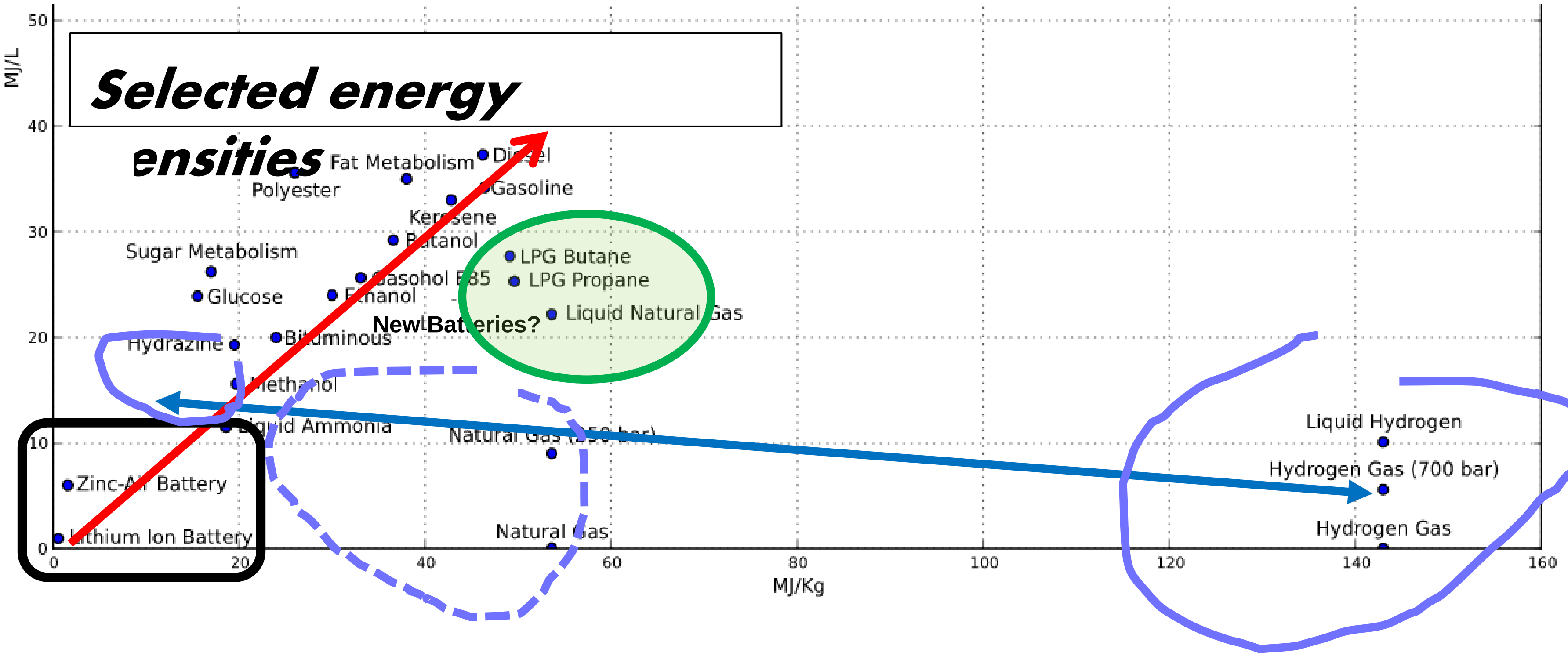
SOURCE: IREC

Selected energy densities



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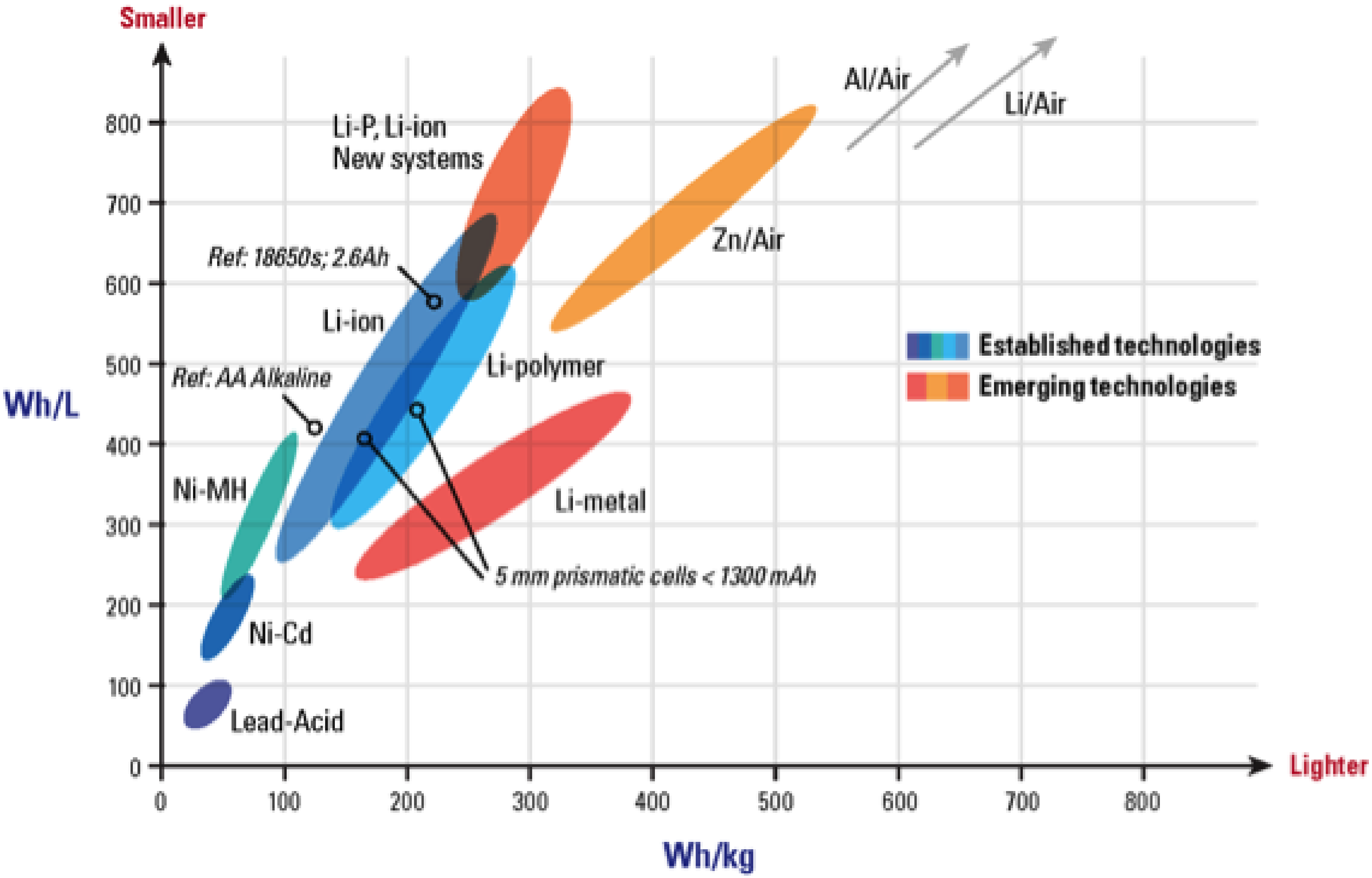

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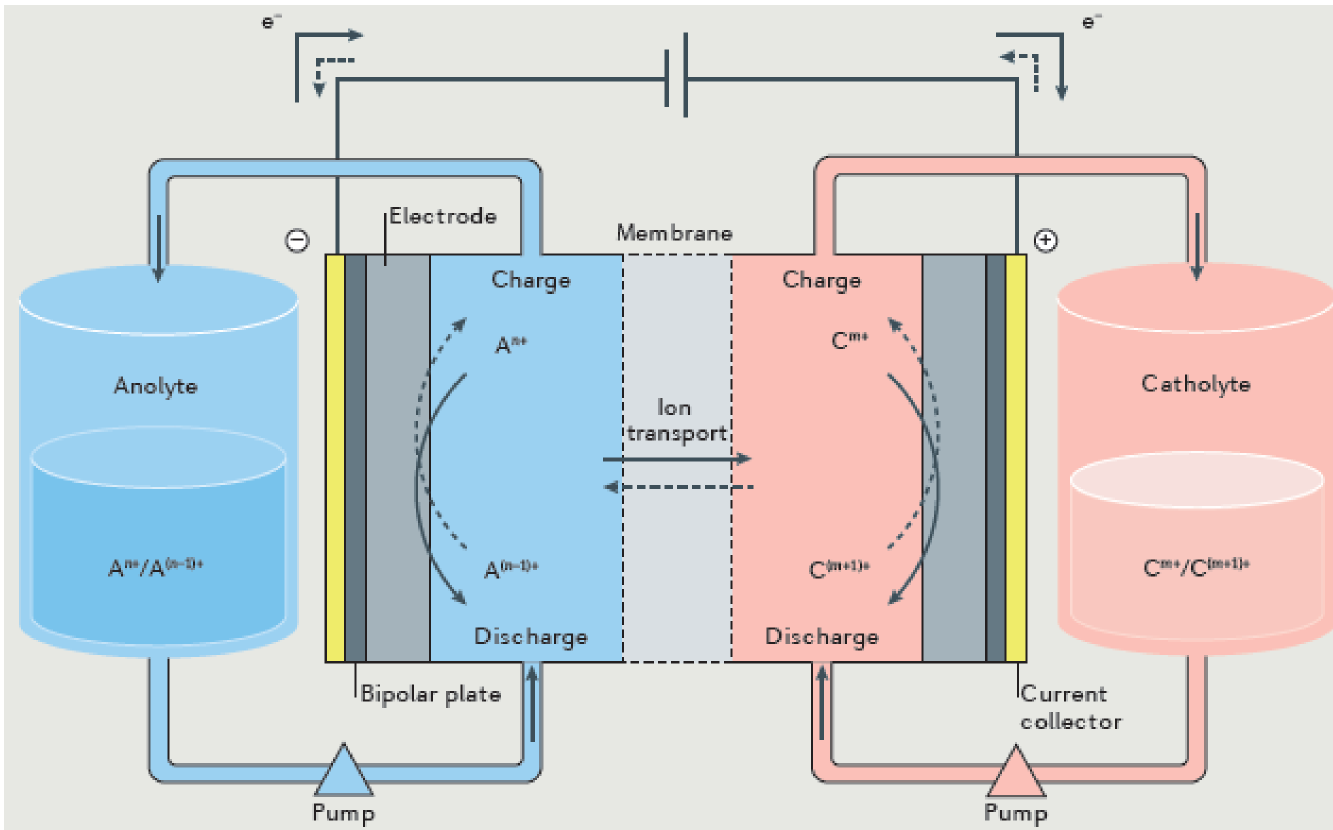
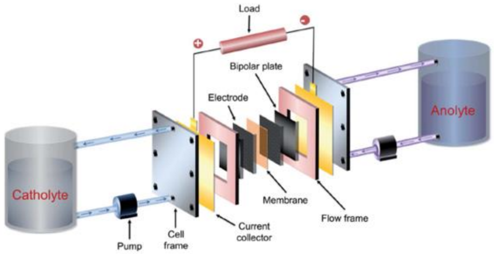
2 ¿QUÉ ES UNA BATERIA DE FLUJO REDOX?

Redox-flow battery (RFB) is a type of rechargeable battery that stores electrical energy in two soluble redox couples





- The basic components of RFBs comprise **electrodes, bipolar plates** (that prevent direct contact between the electrolyte and current collectors), **membranes and two external tanks**.
- The negative electrolyte tank contains anodic redox-active materials dissolved in an electrolyte solution, referred to as the **anolyte**
- The positive tank contains dissolved cathodic redox-active materials, referred to as the **catholyte**. The total energy output depends on the volume of these tanks, which implies that high-solubility catholytes and anolytes are preferred to achieve the high volumetric energy densities.
- These electrolytes are continuously supplied in the stack, and **the redox reactions occur on the surface of the electrode materials that provide redox-active sites**. The oxidized and reduced redox couples on the electrode are accumulated in the external tanks, and charge-balancing ions penetrate through the membrane. Consequently, there are minimal structural changes in the electrode giving rise to **high stability**. The size of the **active area** inside the stack determines the total power output, thus the areal **power density** is an important factor related to the capital cost.
- The performance of RFBs is measured in terms of the Coulombic efficiency, voltage efficiency and energy efficiency. Coulombic efficiency is the ratio of charge and discharge capacities. Voltage efficiency is the ratio of charge and discharge voltages. Energy efficiency is the product of the Coulombic&voltage efficiency.

Key features for reliability:

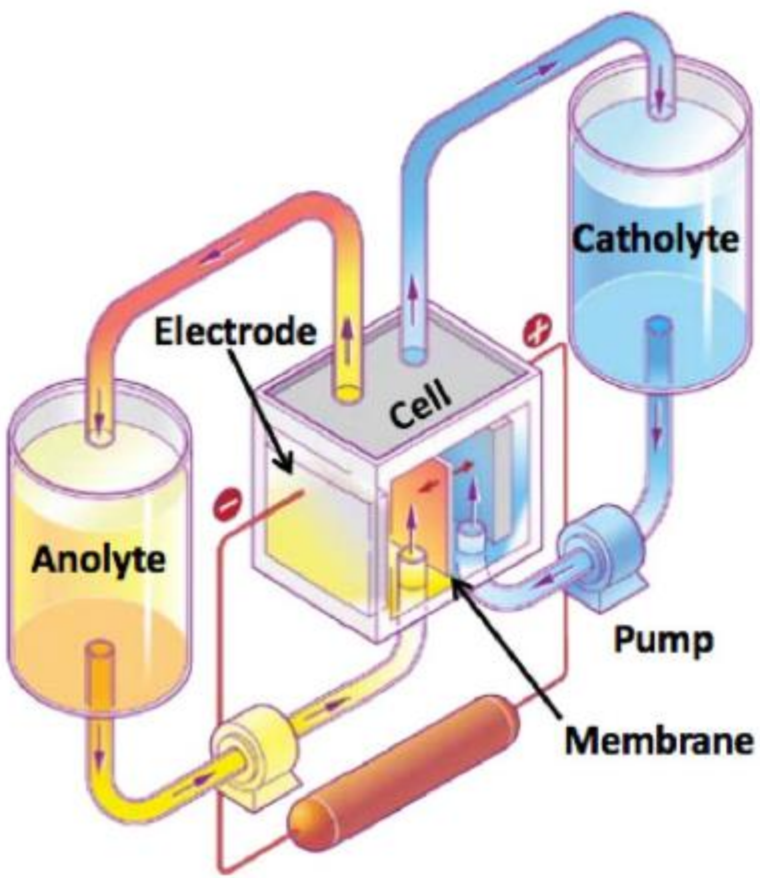
- **Power and energy independent**
  Scalable from 5kW to 10MW, with
  3 to18 hours discharge duration

- **Deep discharge capability**
  Capable of 10,000 cycle life with
  minimal degradation >20 year life

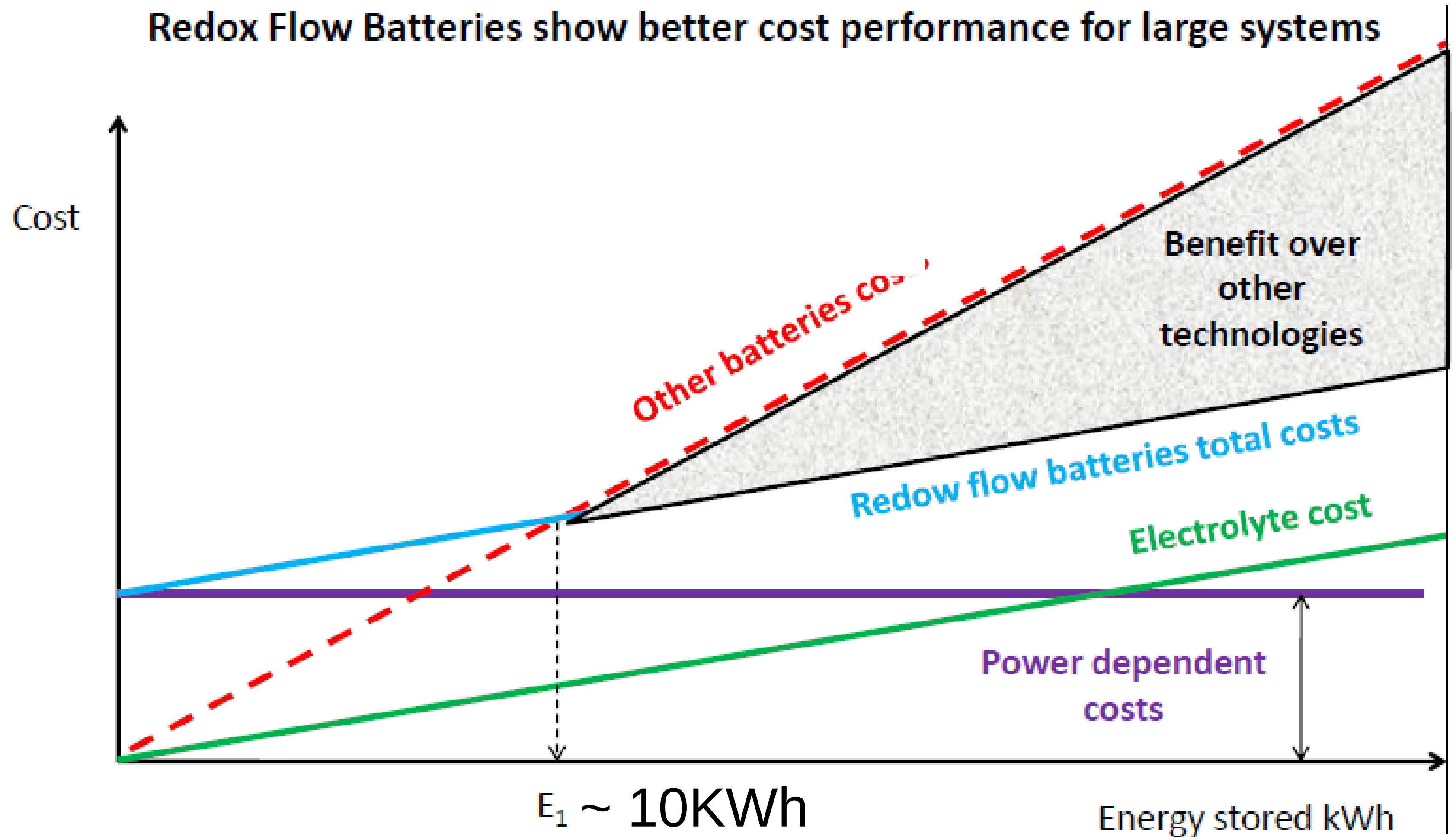
Partial cycles have no effect on system life

- **Safe operation**

Ambient temperature, non-flammable, environmentally sound – zero emissions.



Key Attribute	Conventional	Flow
Energy Density	+	-
System Complexity	+	-
Inherent Safety	-	+
Deep Cycle Life	-	+
Cell-to-cell Uniformity	-	+
Power / Energy Independence	-	+
Capital Cost* ($/kWh)	Inactive materials scale with Energy (kWh)	Inactive materials scale with Power (kW)



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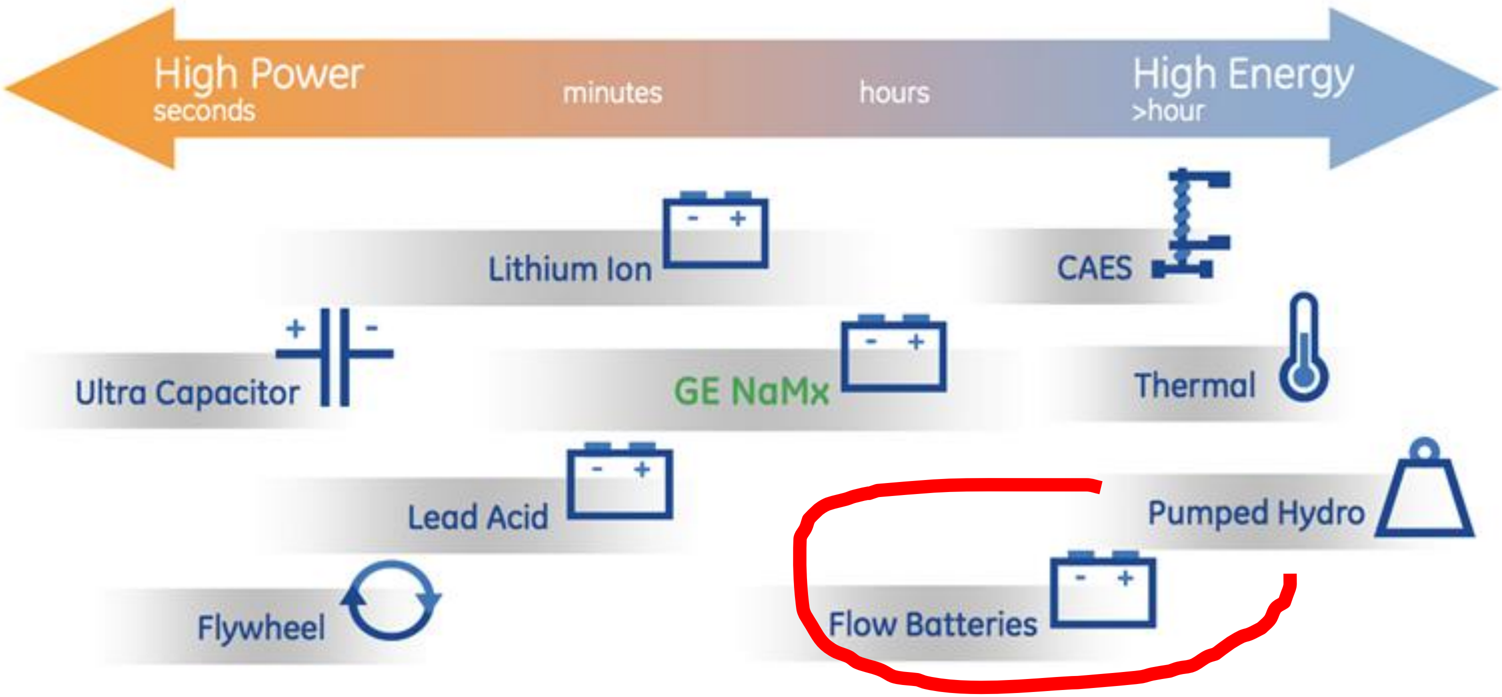

Power: needed to drive at high speeds, Fast charge/discharge
Energy: needed to provide power over extended periods.

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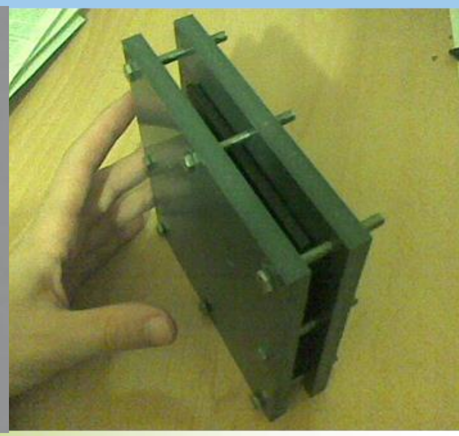
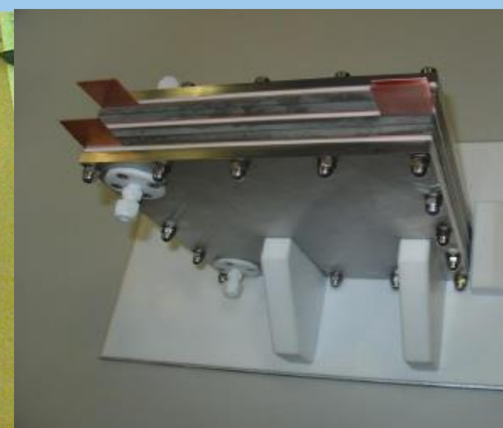
Test facilities for material and stack development

Cell area:

5 cm² **40 cm²** **250 cm²** **700 cm²** **3600 cm²**


Material optimisation

Modelling and Control

Stack and System

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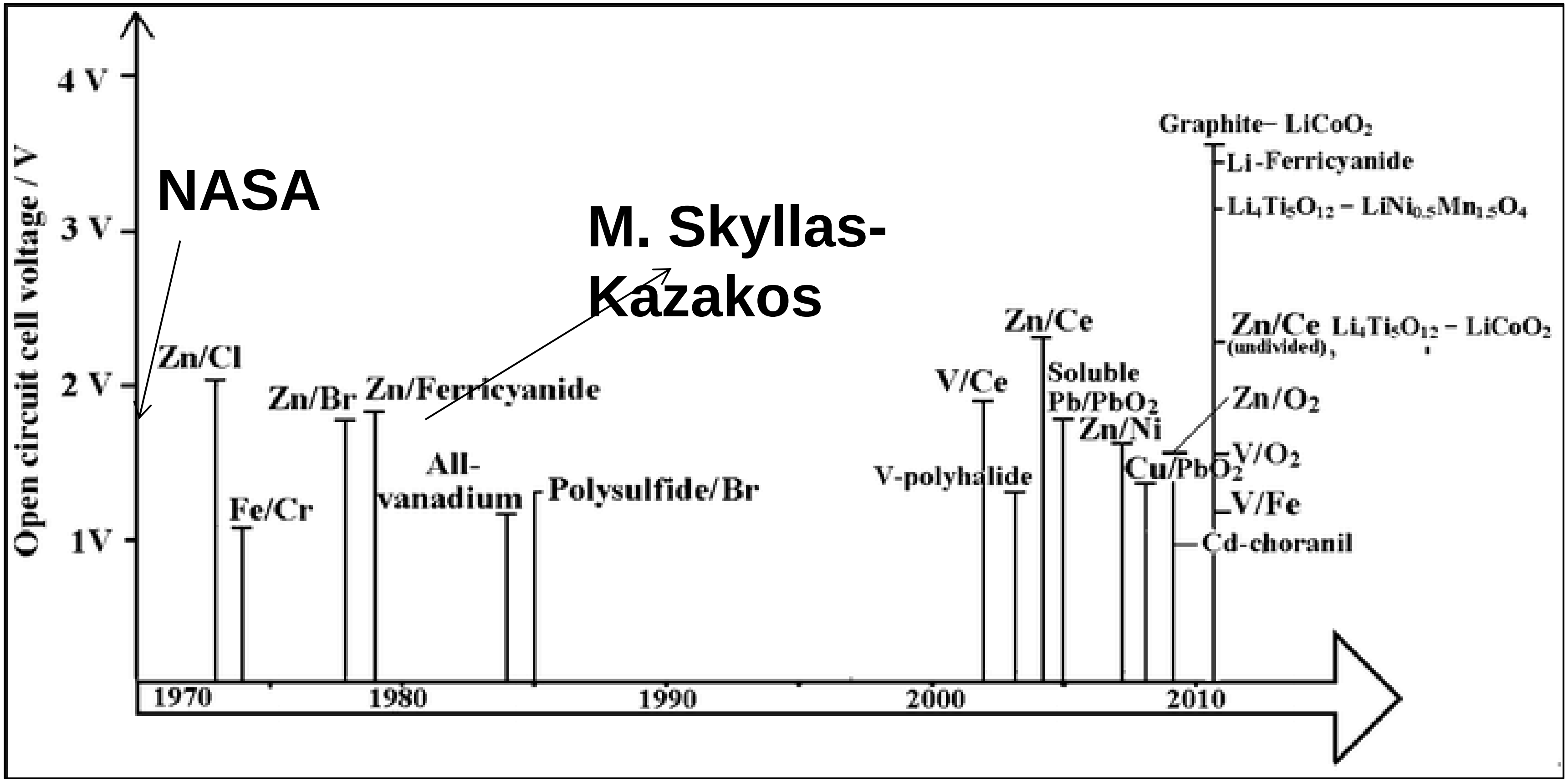
Timeline of the development of RFB over the past 40 years



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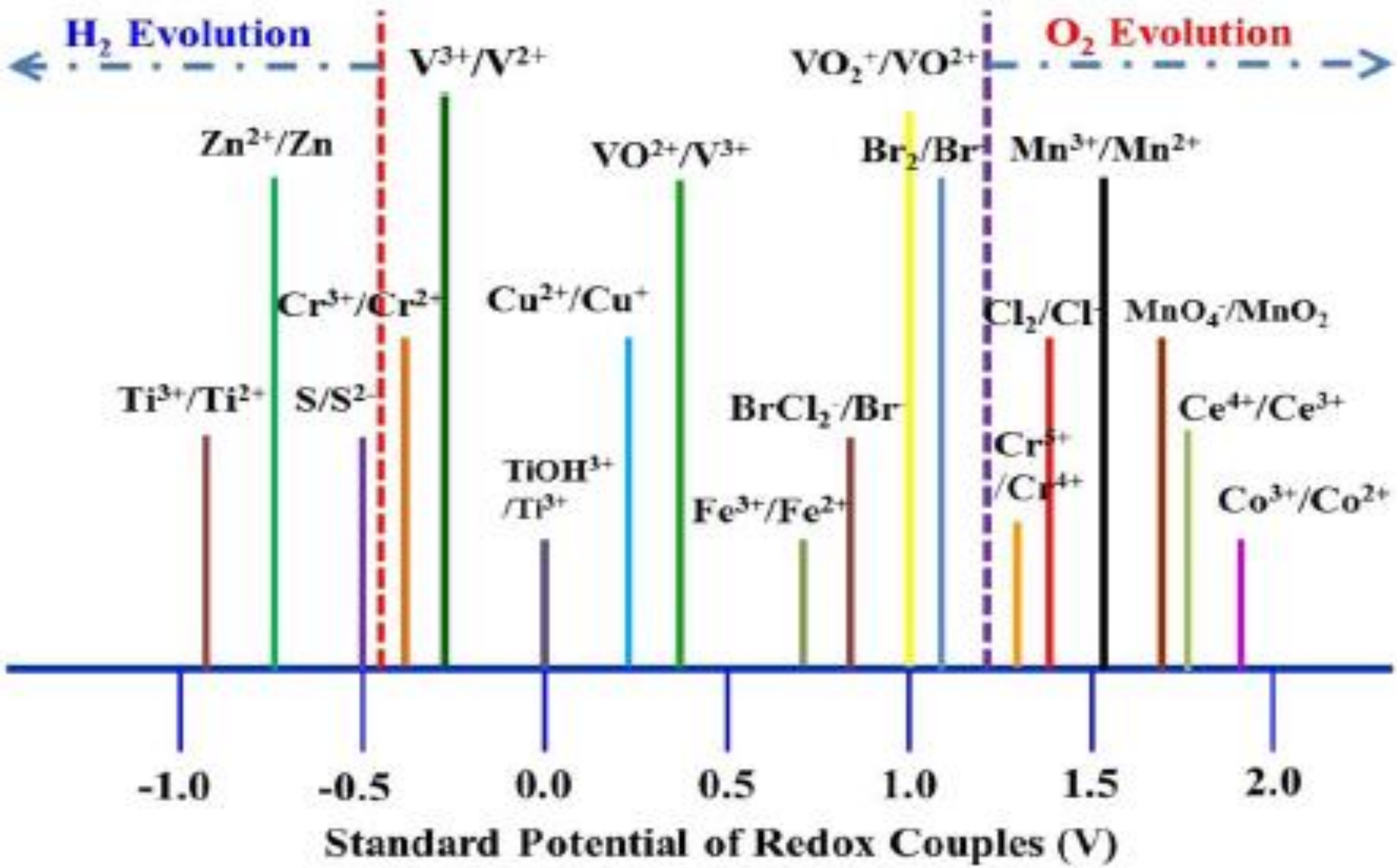
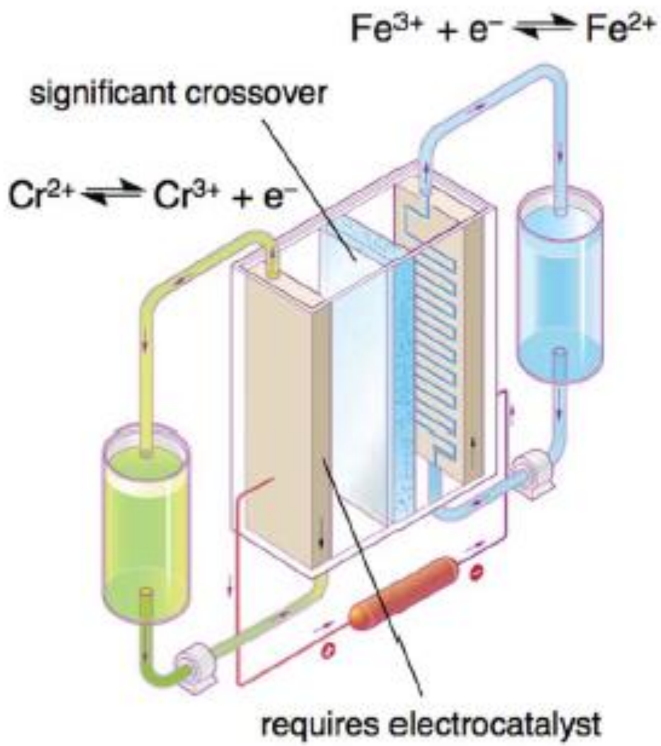
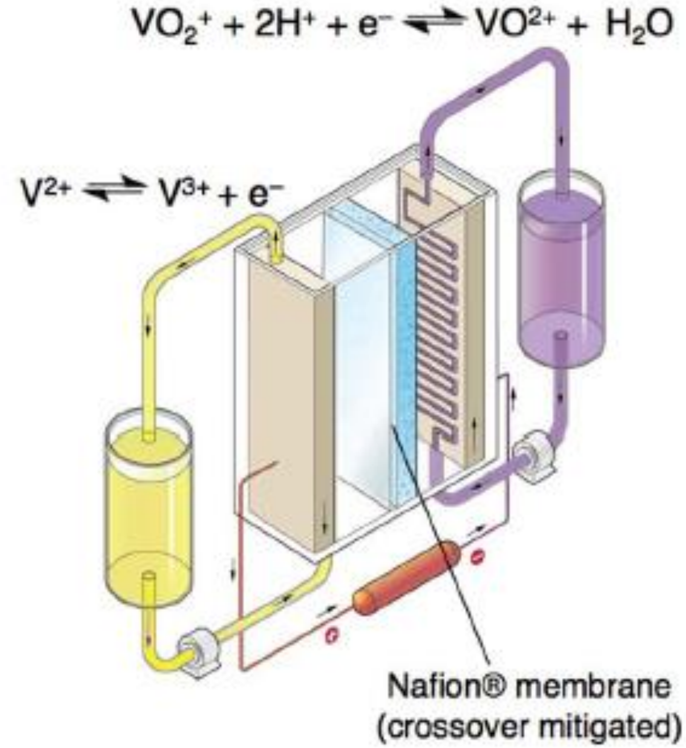


H2 Evolution
O2 Evolution
V3+/V2+
VO2+/VO2+
Zn2+/Zn
VO2+/V3+
Br2/Br-
Mn3+/Mn2+
Cr3+/Cr2+
Cu2+/Cu+
Cl2/Cl-
MnO4-/MnO2
Ti3+/Ti2+
S/S2-
BrCl2-/Br-
Ce4+/Ce3+
Cr5+
/Cr4+
TiOH3+
/Ti3+
Fe3+/Fe2+
Co3+/Co2+
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
Standard Potential of Redox Couples (V)



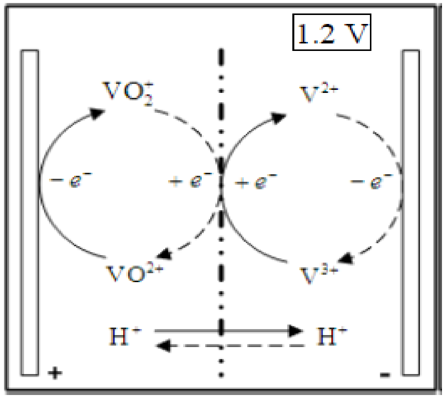
Open Circuit Potentiial (OCP) **1.2 V**



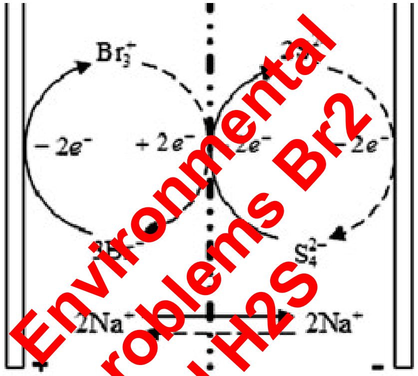
Open Circuit Potential (OCP) **1.3 V**

NEW TRENDS: ORGANICS/POLYMERICS.

All-vanadium

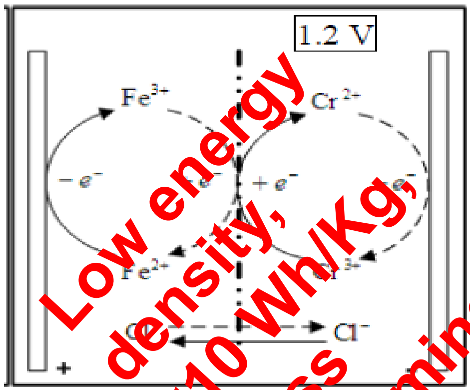


Bromine-polysulphide.



Environmental problems Br2 and H2S

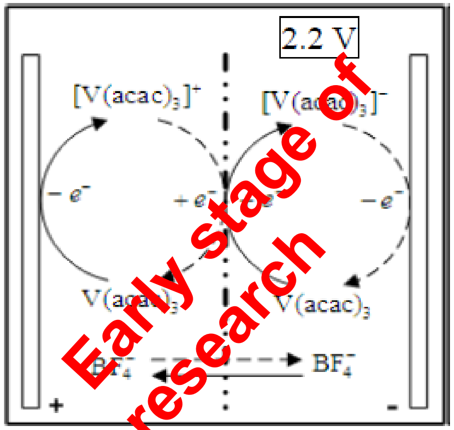
Iron/Chromium



Low energy density, <10 Wh/Kg, cross contamination

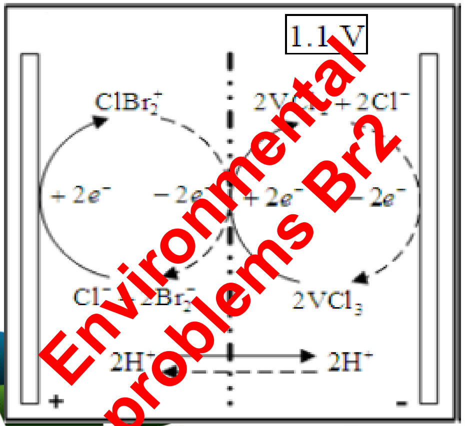
Chemistry	Redox Reactions	Open-Circuit Voltage (OCV)
All-Vanadium (full flow system)	**Negative electrode** $V^{3+} + e^- \underset{Discharge}{\overset{Charge}{\rightleftharpoons}} V^{2+}$ **Positive electrode** $VO^{2+} + H_2O \underset{Discharge}{\overset{Charge}{\rightleftharpoons}} VO_2^+ + 2H^+ + e^-$	1.3
Fe/Cr system	**Negative electrode** $Cr^{3+} + e^- \underset{Discharge}{\overset{Charge}{\rightleftharpoons}} Cr^{2+}$ **Positive electrode** $Fe^{2+} - e^- \underset{Discharge}{\overset{Charge}{\rightleftharpoons}} Fe^{3+}$	1.2
Hybrid flow system Zn/Br$_2$ system	**Negative electrode** $Zn^{2+} + 2e^- \underset{Discharge}{\overset{Charge}{\rightleftharpoons}} Zn$ **Positive electrode** $2Br^- - 2e^- \underset{Discharge}{\overset{Charge}{\rightleftharpoons}} Br_2$	1.8

Non aqueous vanadium



Early stage of research

vanadium – bromide



Environmental problems Br2

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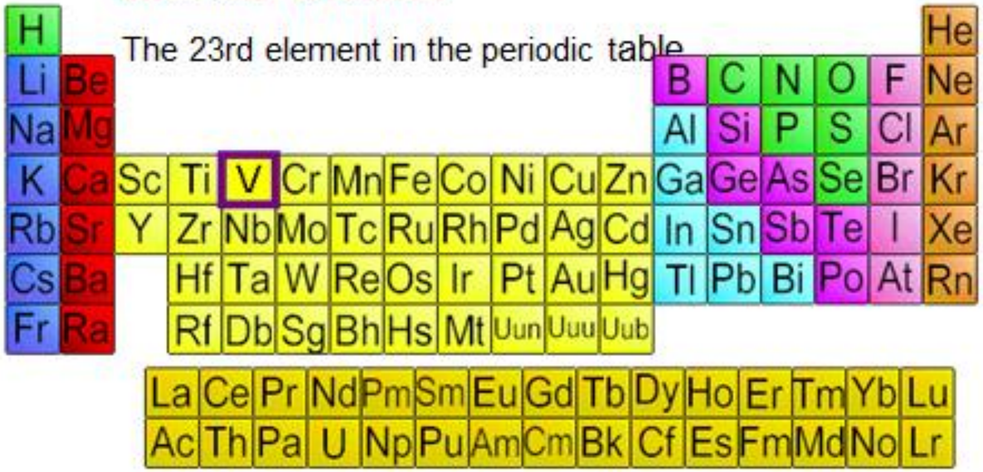
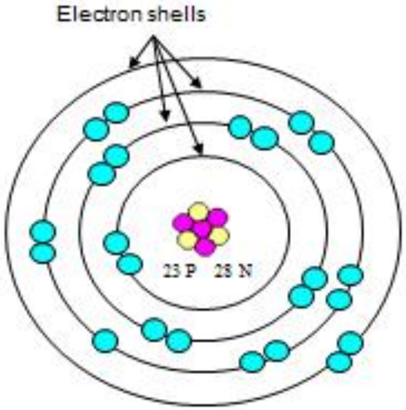
Vanadium – What is it ?

The 23rd element in the periodic table

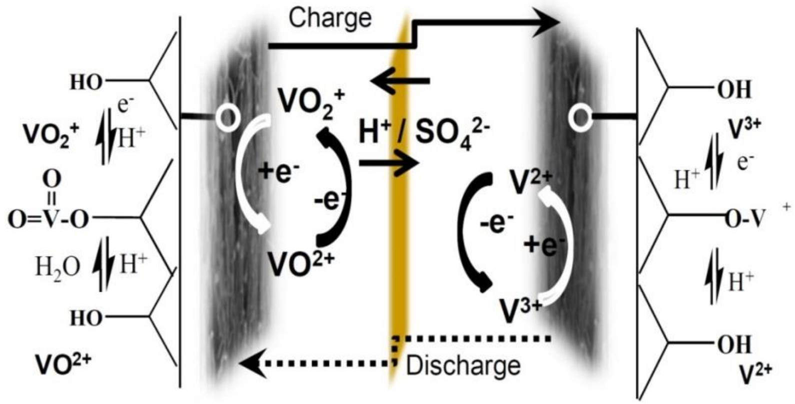




Vanadium is a silverish *transition metal* (the valence electrons exist in more than one shell). In normal states, vanadium atoms have 23 protons, 23 electrons, and 28 neutrons. Very High Columbic Efficiency -98%

All-liquid flow batteries
Inorganic flow batteries

Vanadium Redox Flow Battery (VRB)



SINCE SULFURIC ACID SOLUTION is used as supporting electrolyte, carbonaceous material are preferably chosen as electrode for :
-high surface area
-chemical stability
-wide potential window

Characteristics

- same metal used in both compartments: no crossover contamination

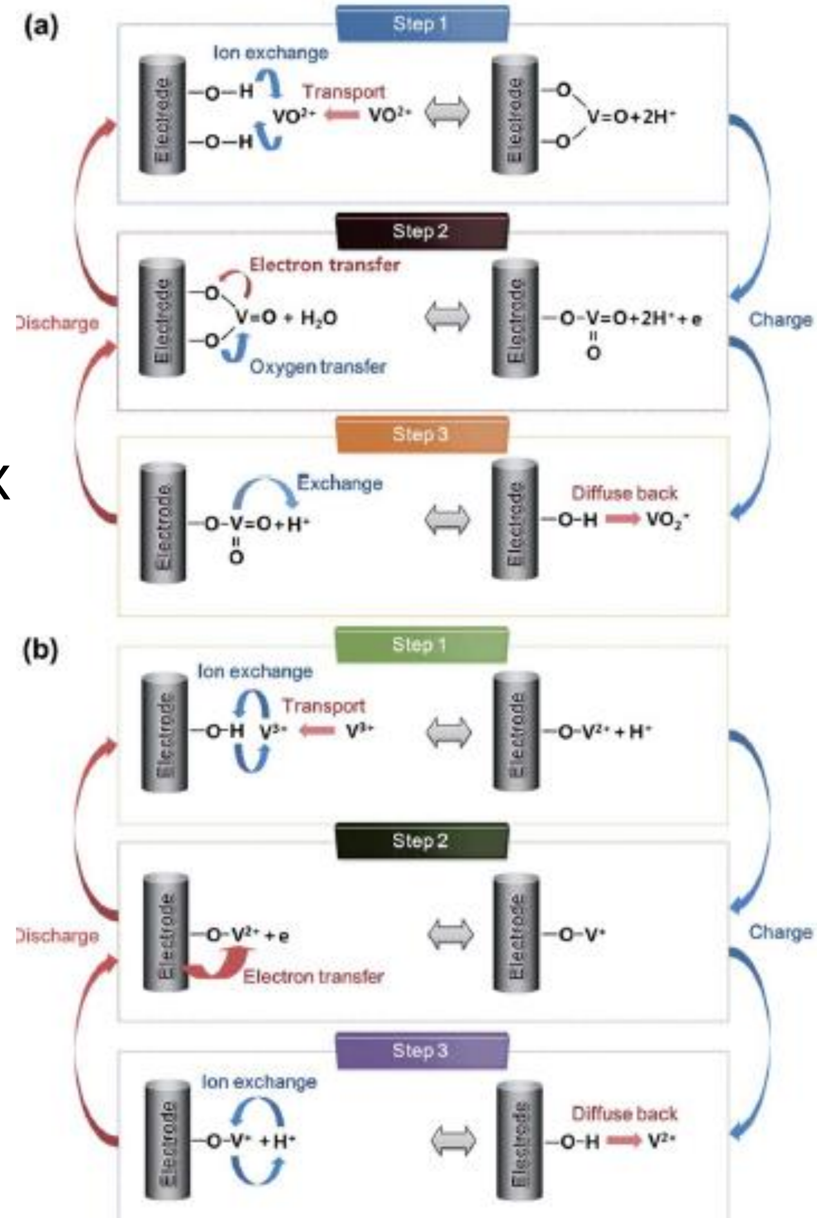
- catholyte (1-2 M $VOSO_4$ + 2-5 M H_2SO_4), anolyte (0.5-1 M $V_2(SO_4)_2$ + 2-5 M H_2SO_4), proton – or anion-exchange membrane

- V_2SO_4 solution protected with N_2 atmosphere

Disadvantages
Poor electrocatalytic reaction
Low power and energy density
Operational temperature is limited to 40 ^{0}C

side	Redox process	E_{red}°ocv/V (vs SHE)
+	$VO_2^+ + 2H^+ + e \leftrightarrows VO^{2+} + H_2O$	1.00
-	$V^{2+} \leftrightarrows V^{3+} + e$	0.26
		Cell voltage: 1.26V

Schematic illustration of the redox reaction mechanism proposed by Skyllas-Kazacos et al. for
(a) VO2+/VO2+ redox couple in the catholyte,
(b) V2+/V3+ redox couple in the anolyte on the surface of the carbon felt electrode in VRFB



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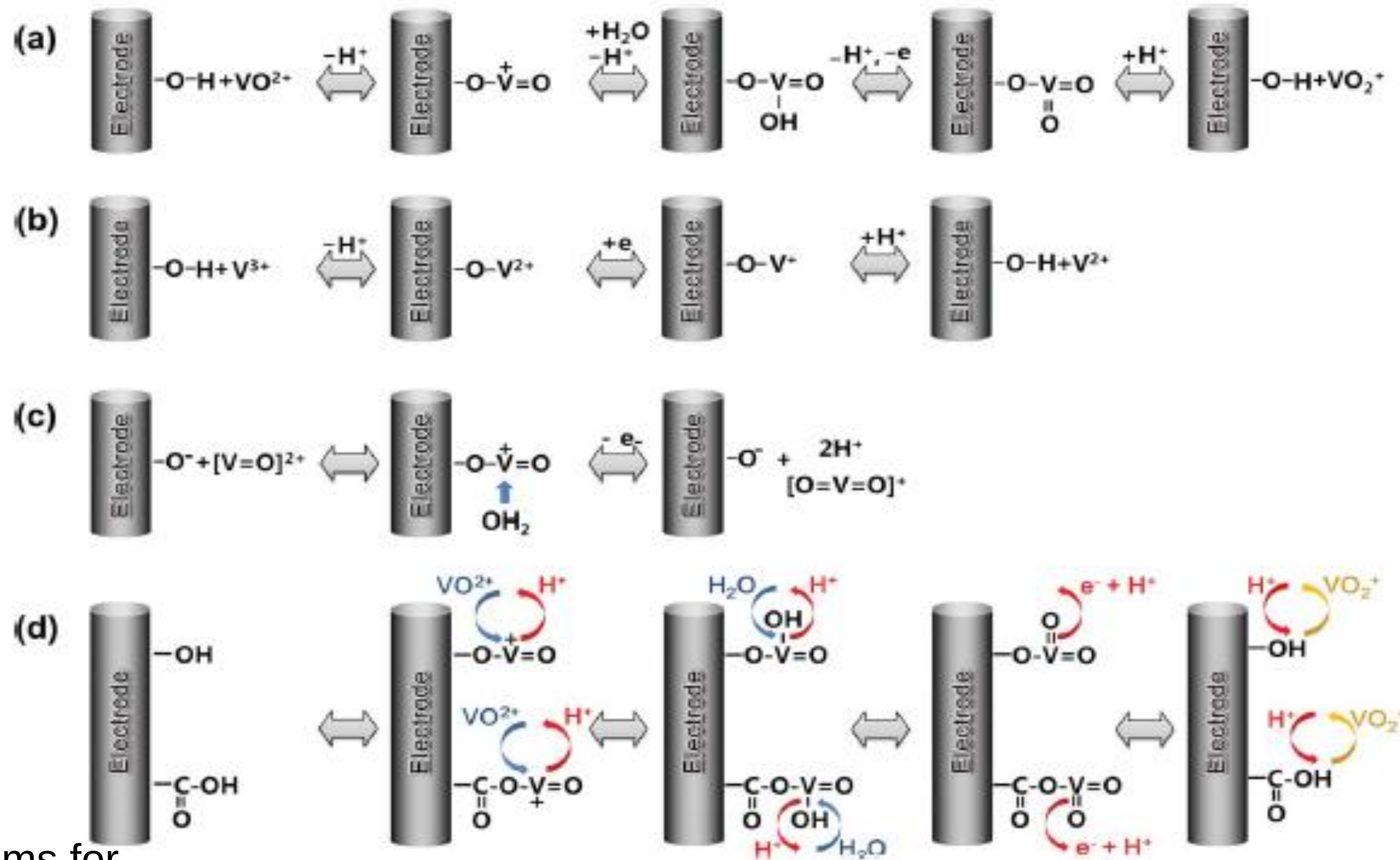

Redox reaction mechanisms for

(a) VO2+/VO2+ redox couple (in the catholyte)

(b) V2+/V3+ redox couple (in the anolyte) on the surface of a carbon fiber electrode, as suggested by Li et al.;

(c) the mechanism for the VO2+/VO2+ redox couple on the surface of the carbon paper electrode proposed by Wu et al.

(d) the mechanism for the VO2+/VO2+ redox couple with –OH and –COOH functional groups proposed by Qiu et al.

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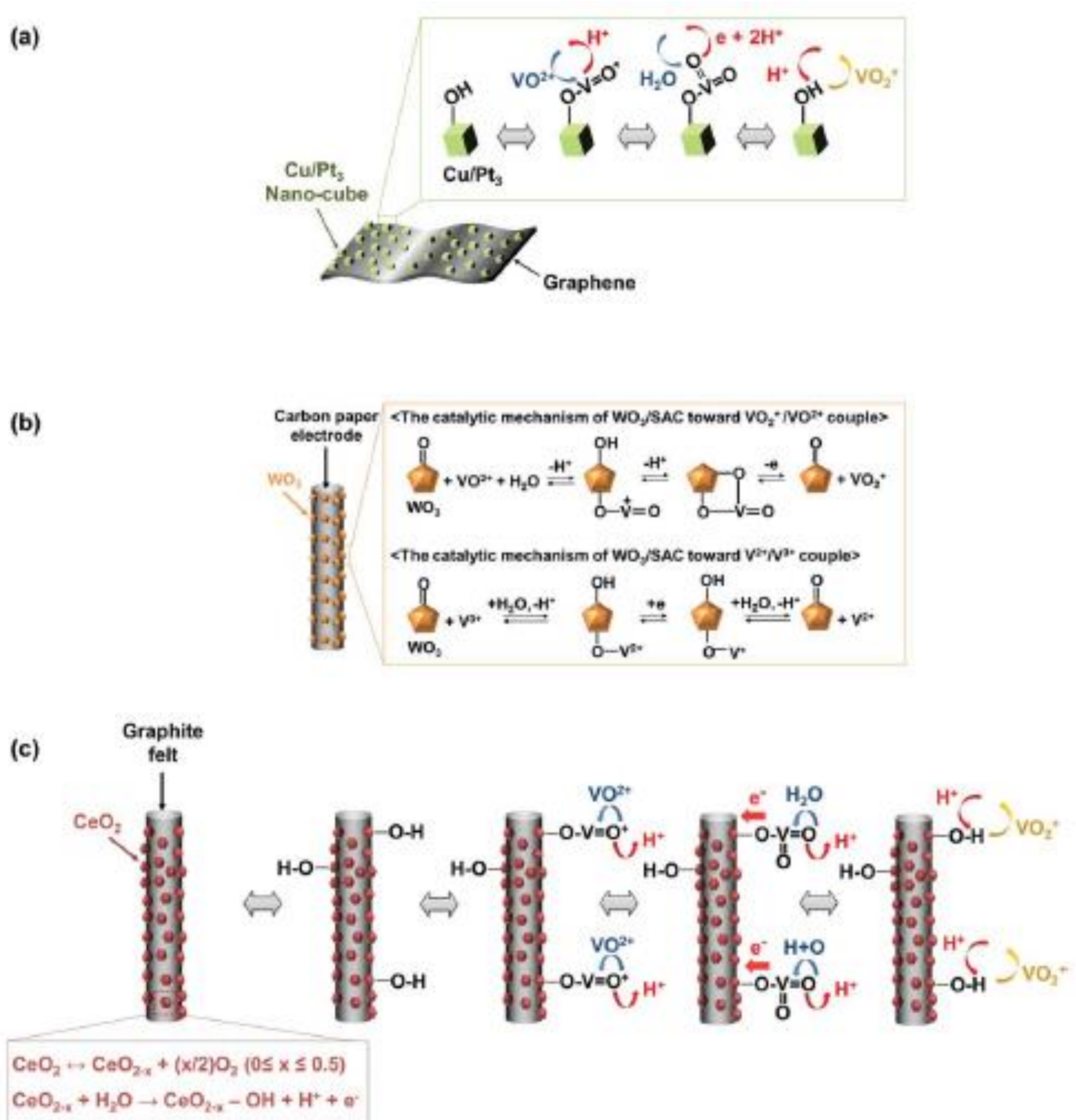
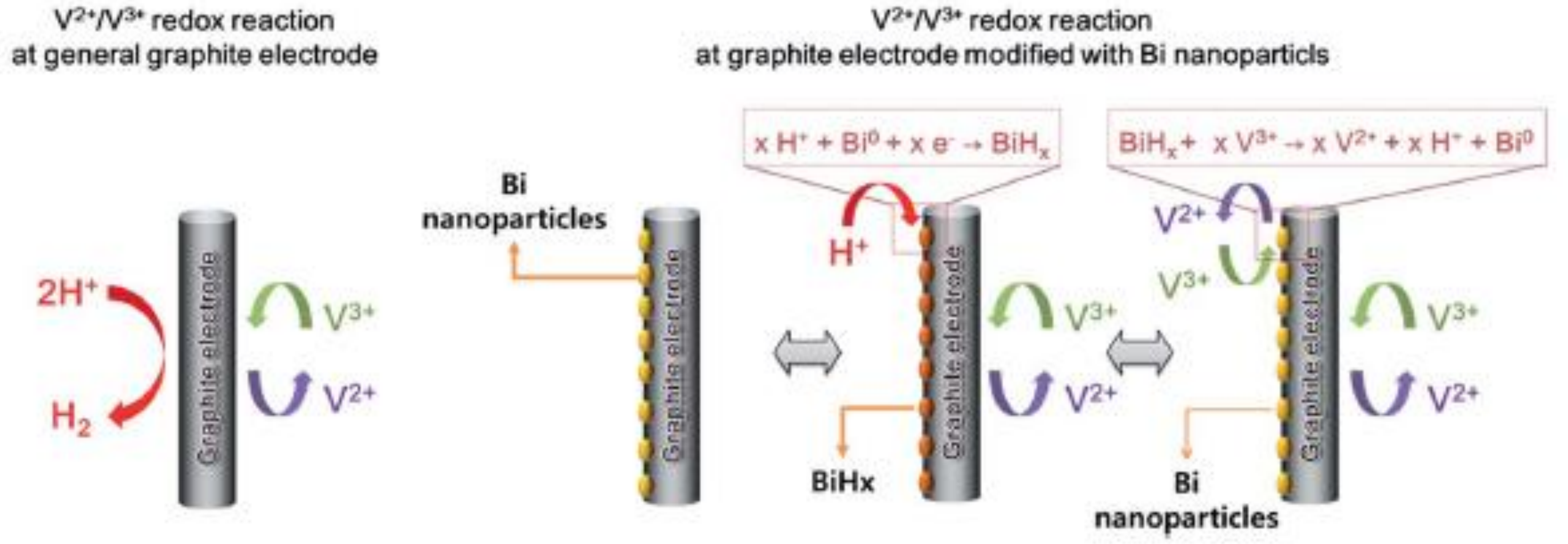
Schematic diagrams of the catalytic reaction mechanisms of

(a) CuPt3 catalyst developed by Flox et al.,

(b) (b)WO3/SAC catalyst developed by Zhang et al.,

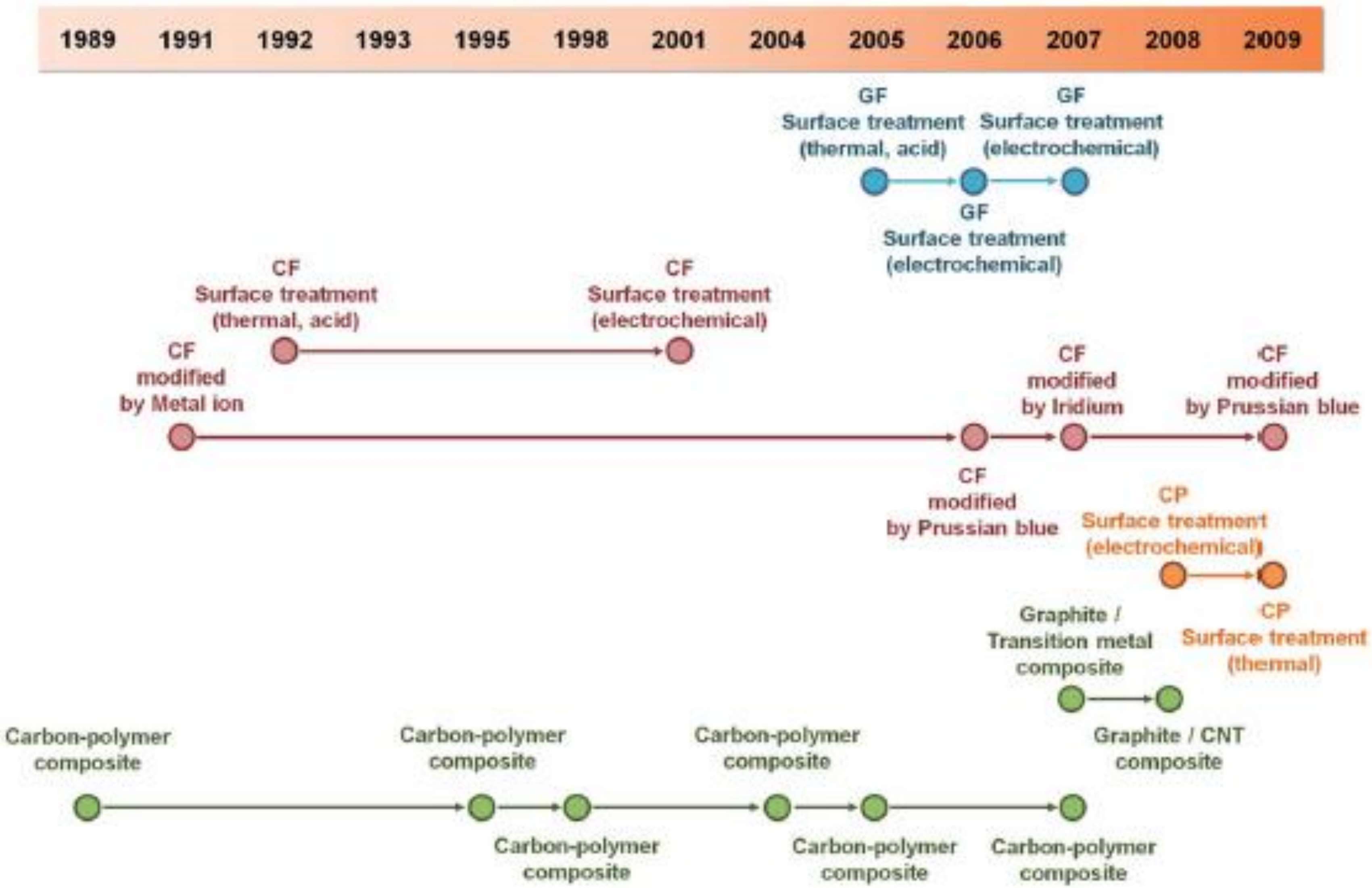
(c) CeO2 catalyst felt electrodes developed by Qiu et al.





Schematic diagram of the mechanism proposed by Blanco et al. for the V2+/V3+ redox reactions occurring in the presence of Bi nanoparticles on the carbon felt electrode

Historical flow chart for research on electrodes for the VRFB



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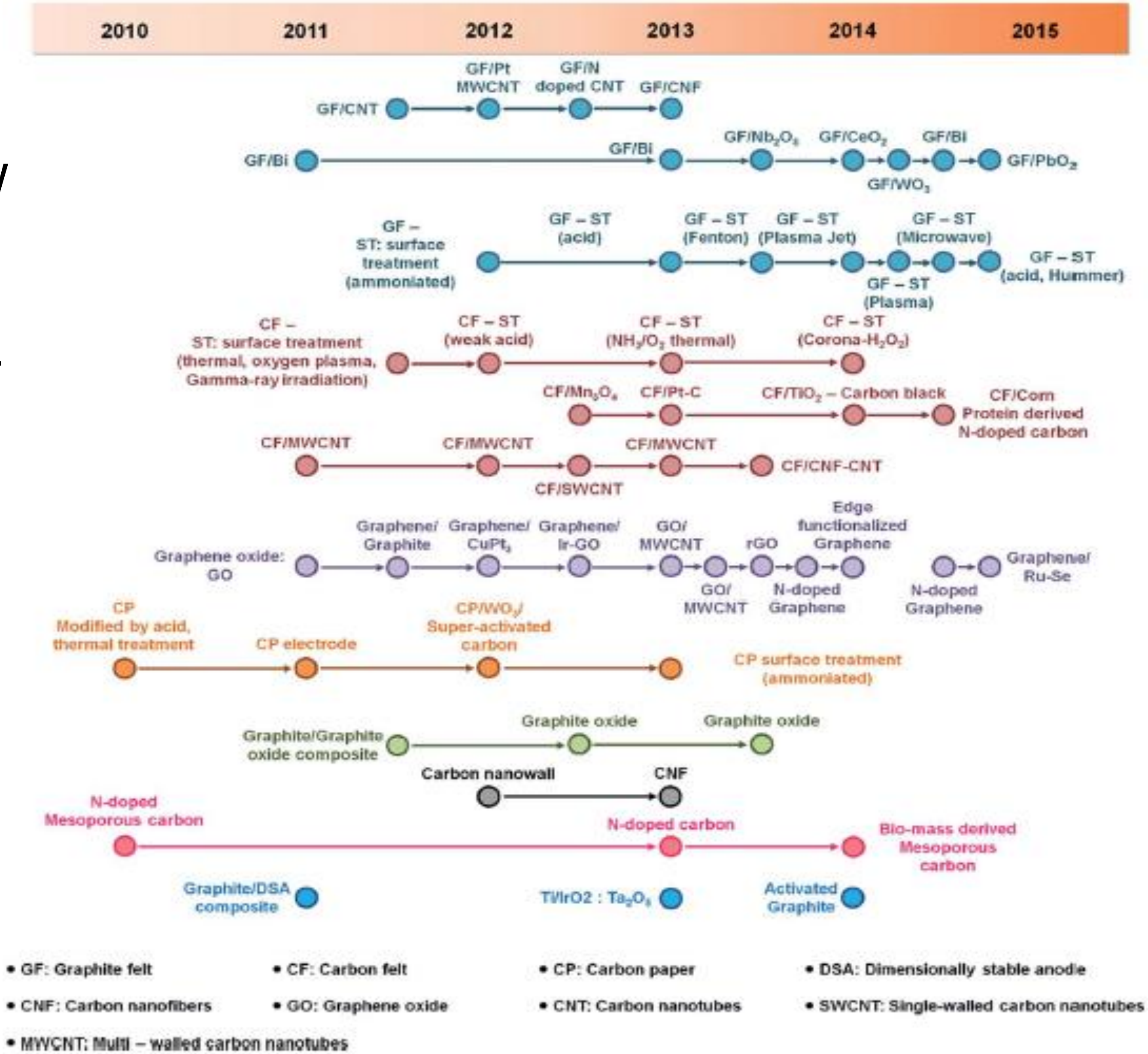
Historical flow chart for research on electrodes for the VRFB



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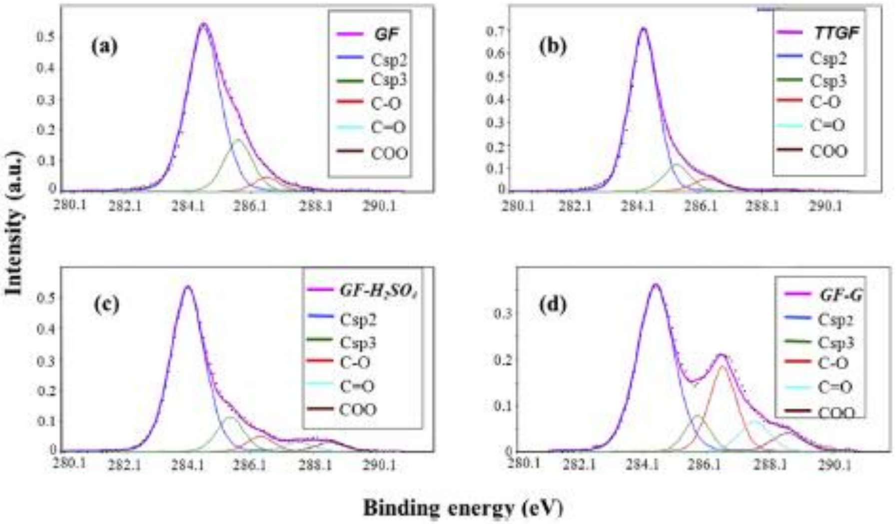
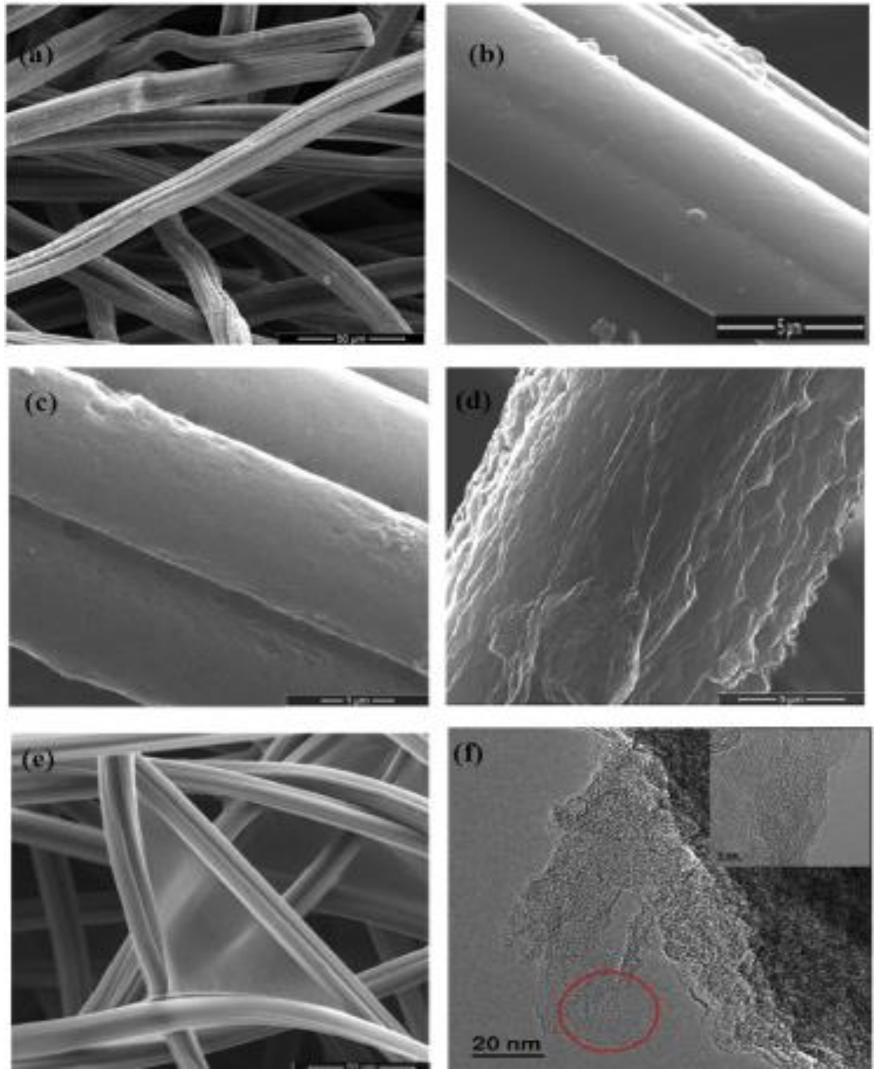


Curve fitting of C1s XPS spectra of
(a) GF,
(b) (b) TTGF,
(c) (c) GF-H2SO4 and
(d) GF-G.



SEM images of (a) GF (b) TTGF (c) GF-H2SO4 and (d, e) GF-G. (f) HRTEM image of an interface region of GF-Graphene.

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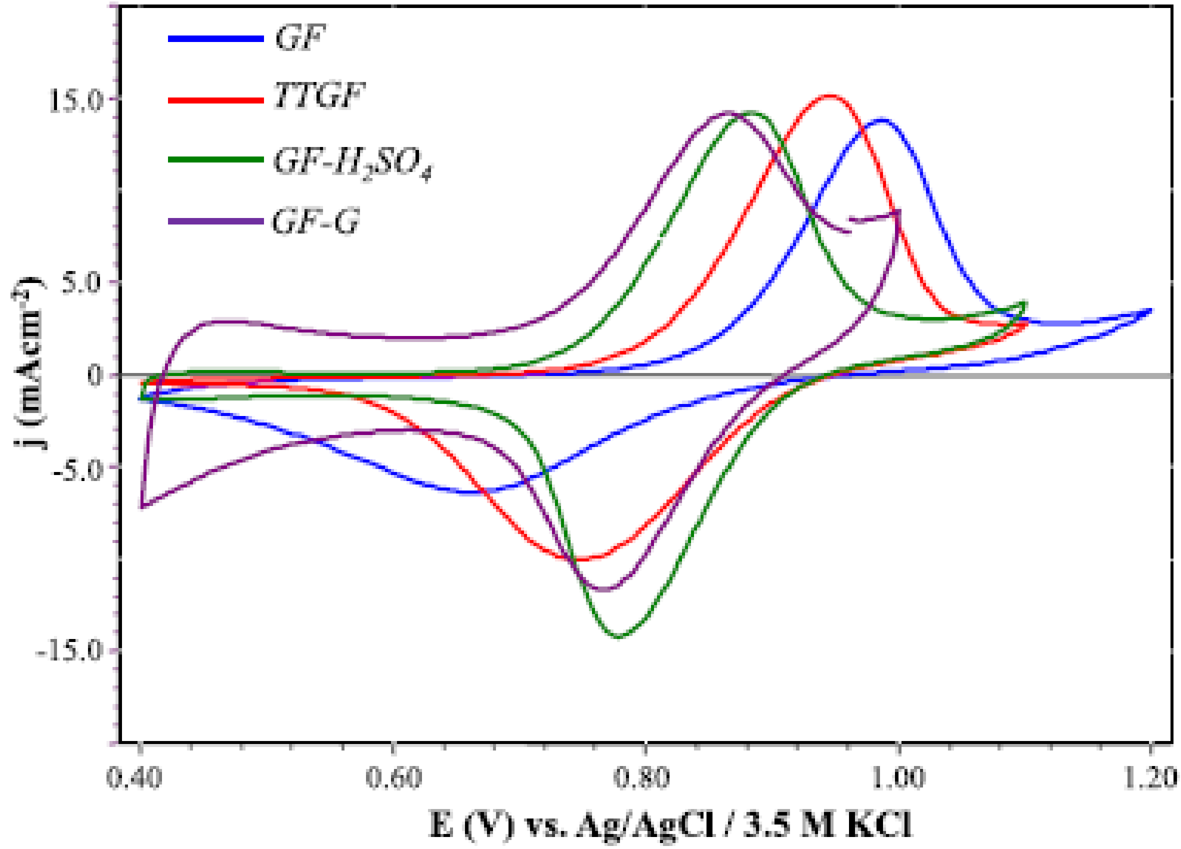

CVs recorded (starting from the OCP and with a positive scan direction) in a 0.05 M VOSO4/1.0 M H2SO4 solution at a scan rate of 1 mV s1 on the different graphite felt electrodes.

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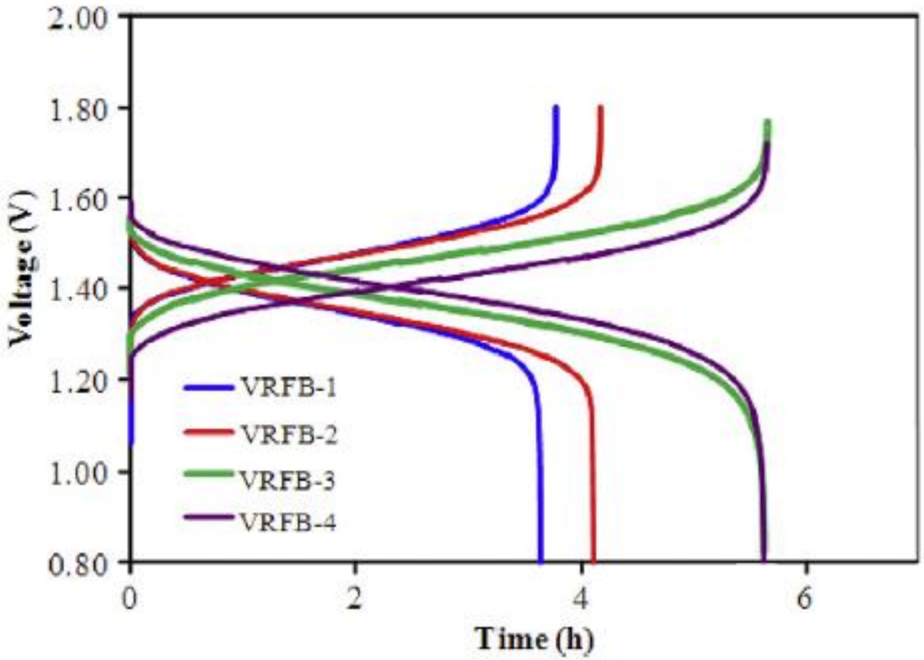
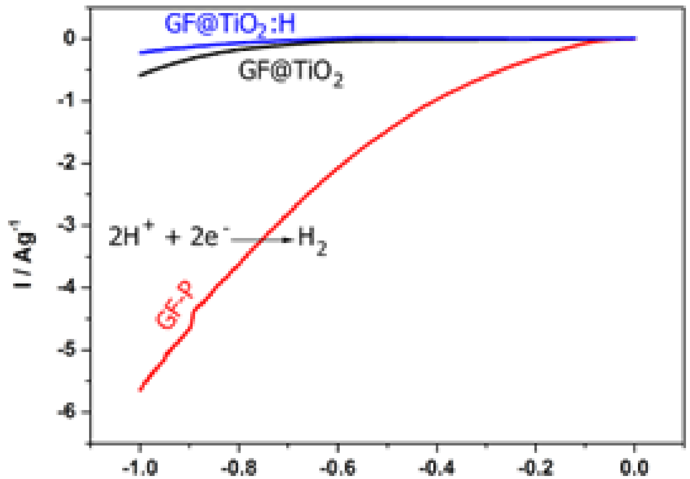
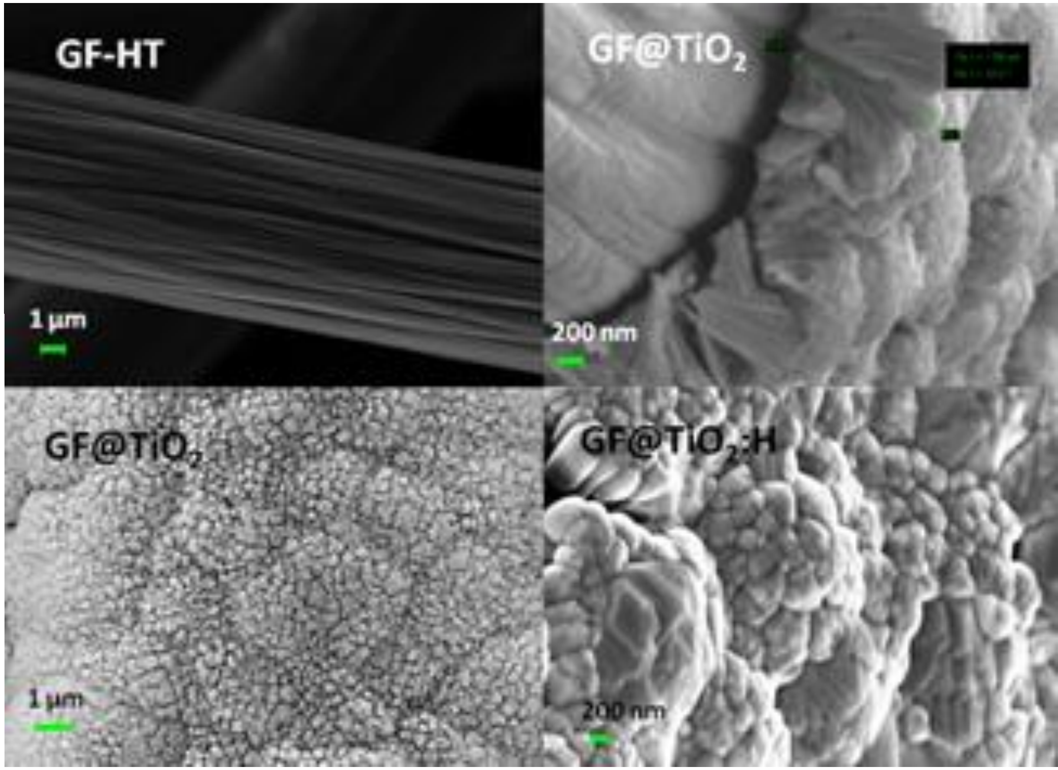
Cell test	η_C (%)	η_V (%)	η_E (%)	DC (AhL^{-1})
GF-H_2SO_4/GF (VRFB-1)	91.1	91.5	83.3	8.7
GF-H_2SO_4/TTGF (VRFB-2)	98.6	90.6	89.3	10.2
GF-H_2SO_4/GF-H_2SO_4 (VRFB-3)	99.5	91.1	90.5	13.0
GF-H_2SO_4/GF-G (VRFB-4)	99.5	96.3	95.8	14.1



Charge/discharge profiles of the four VRFB cells operating at 25 mA cm2.

Linear sweep voltammetry (LSV) of pristine graphite felt, GF@TiO2 and GF@TiO2:H electrodes using a 1M sulphuric media with potential window of 0 to -1V





SEM images of the

(a) core graphite GF-P;

(b) core/shell structure showing a cross section of the TiO2 coating layer;

(c) morphology details of the coating layer of the GF@TiO2 electrode;

(d) coating layer of the GF@TiO2:H electrode

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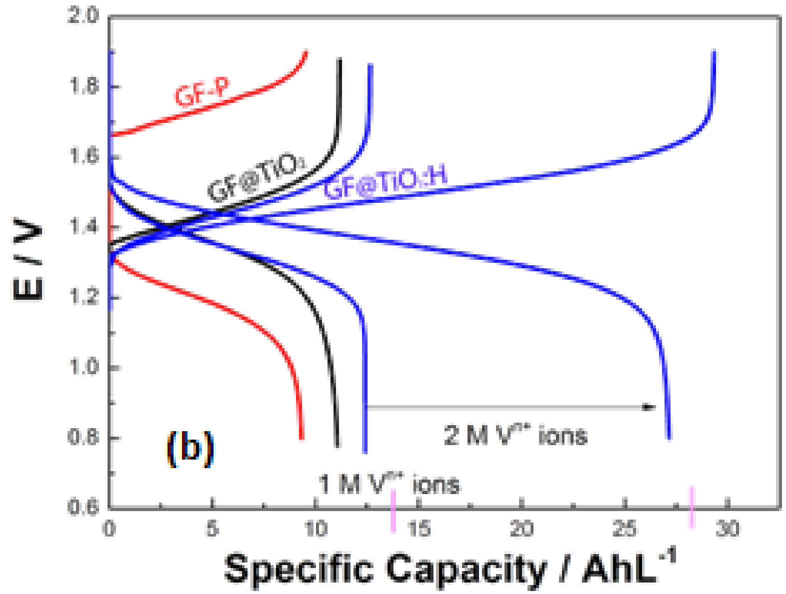
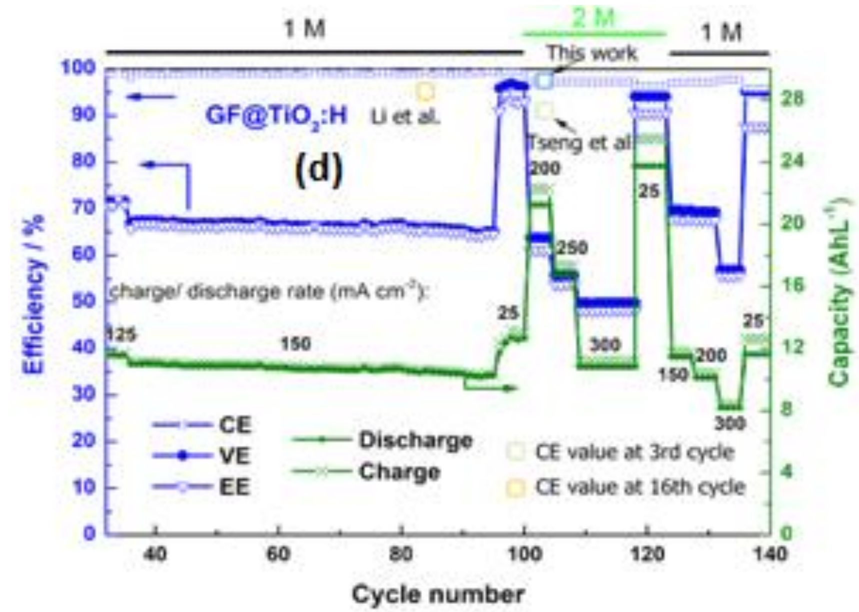
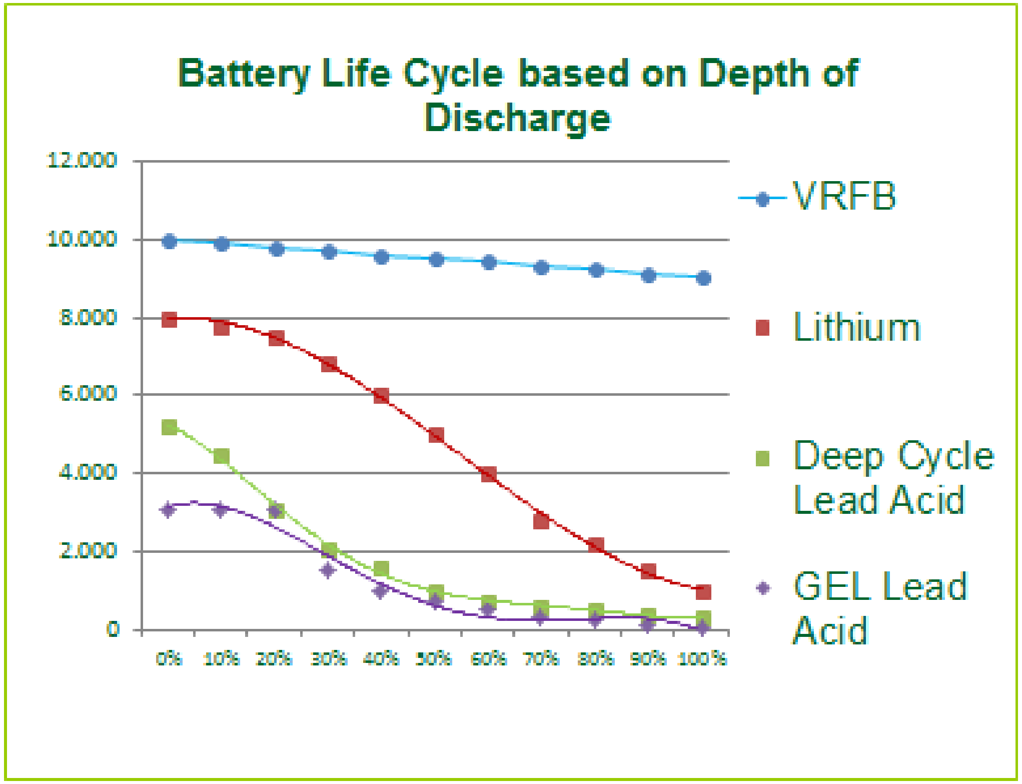




Galvanostatic charge/discharge profile at 25 mAcm-2 using 1 M and 2 M Vanadium ion in 3M H2SO4 as electrolyte.

long-term stability of the GF@TiO2:H electrode



- **Low LCOE >20 year life**
  - Lowest cost over life in class
  - Modular from 5kW to 5MW to match loads, scale duration from hours to days
  - Stack life > 10,000 cycles, electrolyte indefinite life, re-usable & recyclable
- **Performance**
  - Deep discharge cycles, uses 100% of available capacity
  - Charge retention, almost indefinite in standby mode
  - 75-85% round trip efficiency
  - Partial cycles have 0 effect

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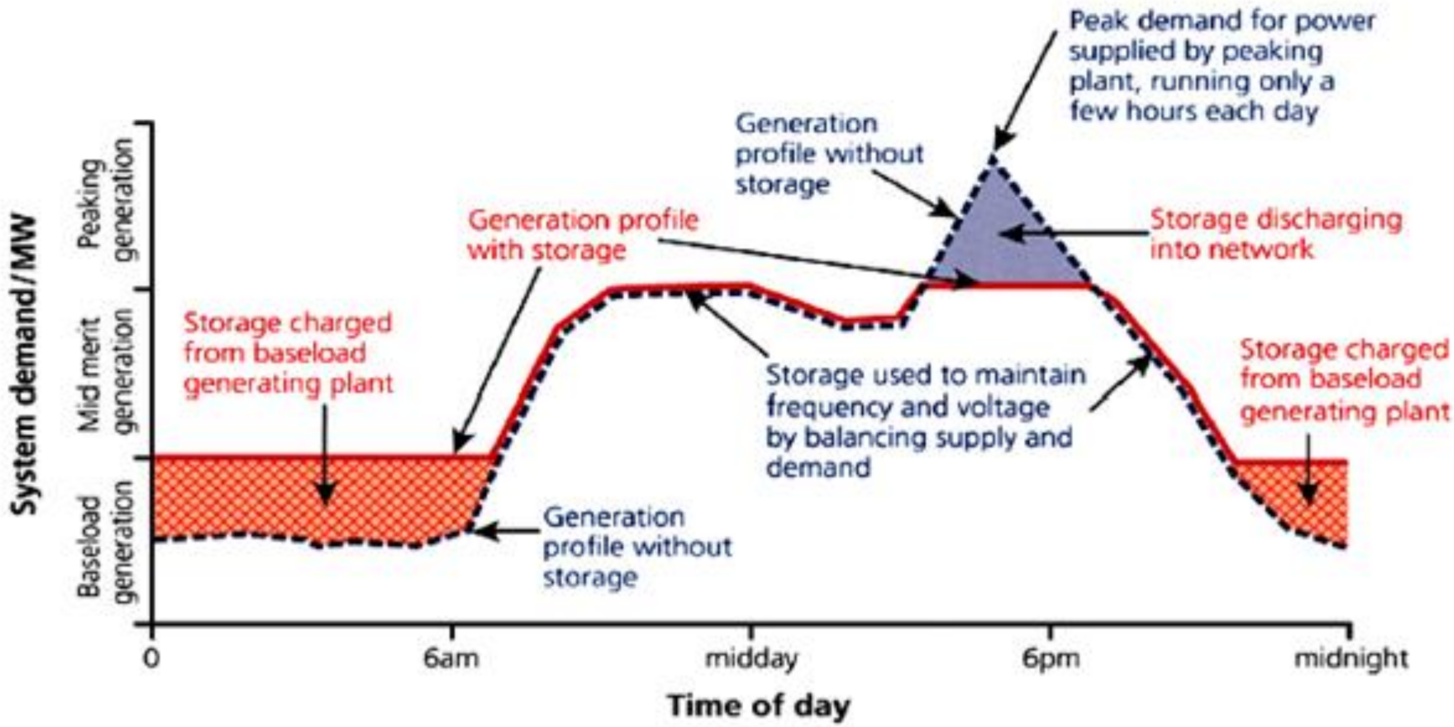
VRFB Applications – Grid balancing services

Typical Energy Storage application for grid peak shaving with baseload power



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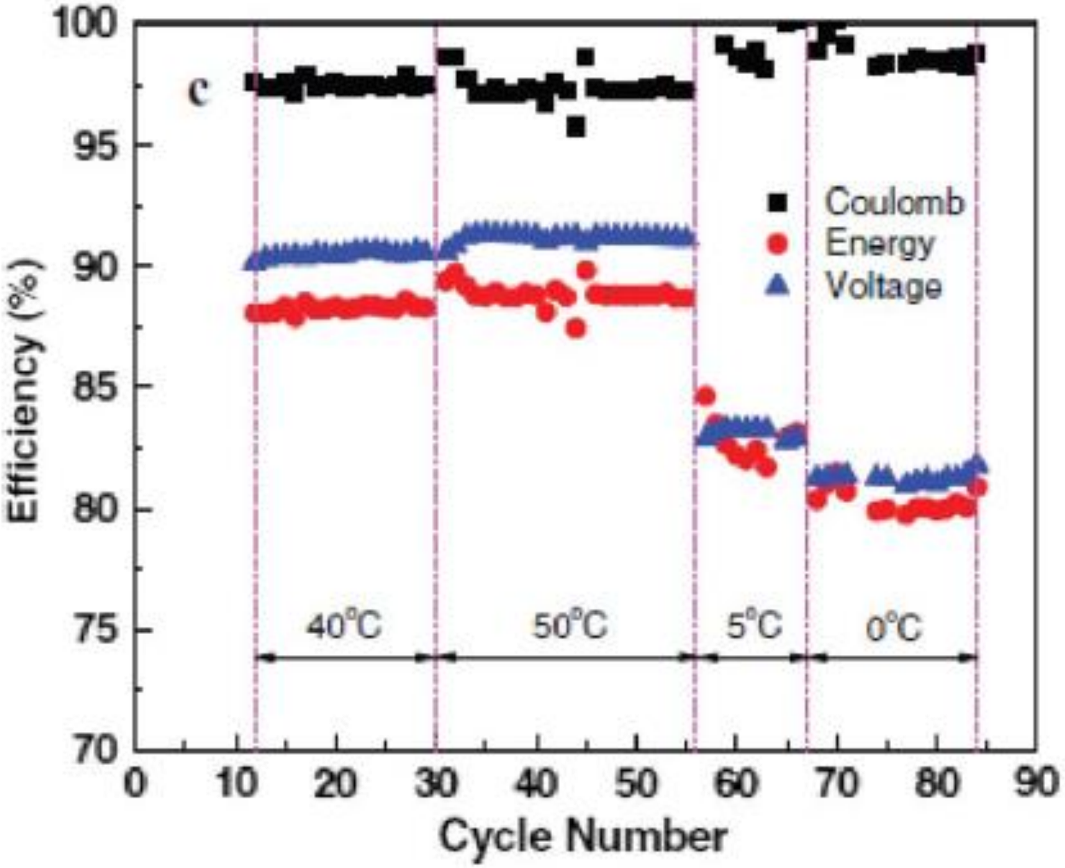
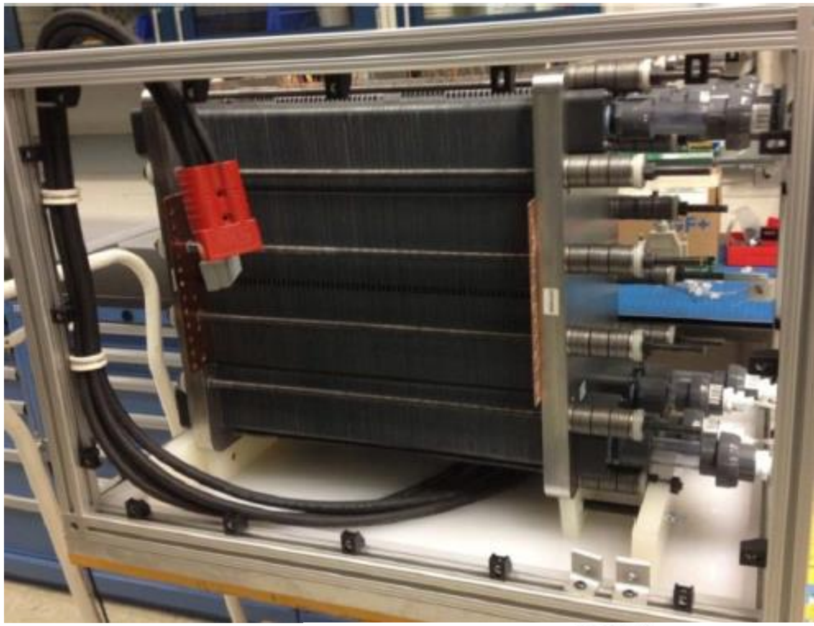
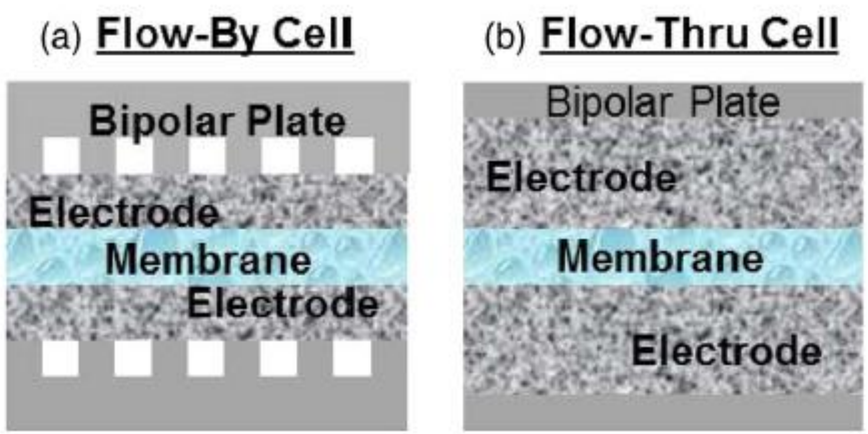
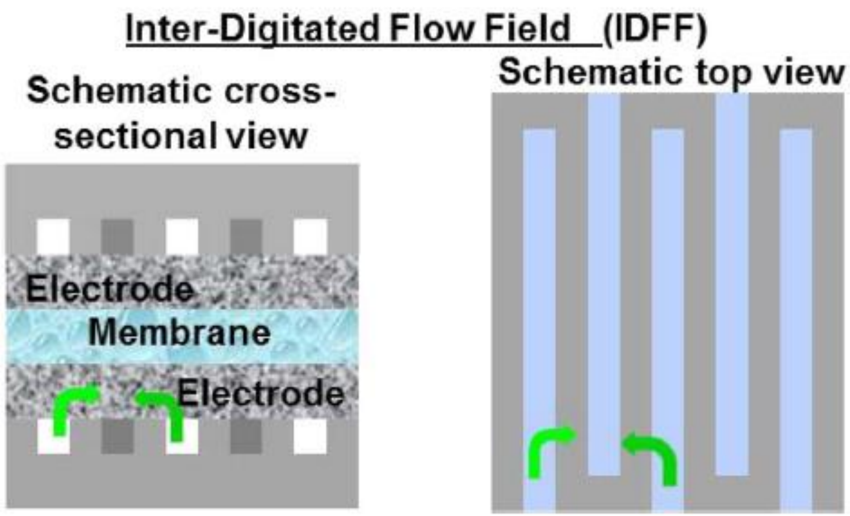


Performance of a mixed electrolyte all-vanadium redox cell cycled at 50 mA/cm2 between 1.267 and 1.60 V

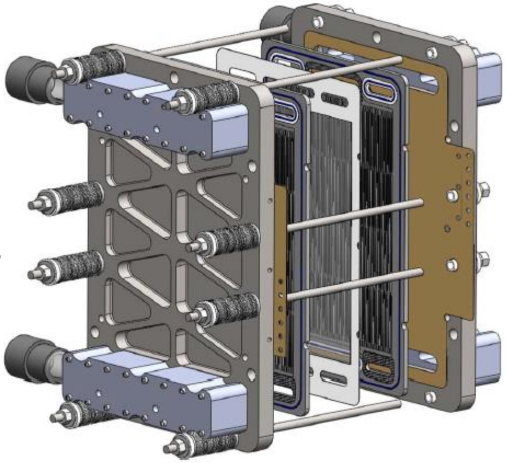
Schematic cell cross-section depictions of different electrode and flow-field configurations used in conventional RFB cells: (a) flow-by geometry, or PFF; and (b) FT geometry







Schematic depictions of IDFF configurations used in some high power density RFB cells, which results in a mixture of forced-convective flowthrough the porous electrodes and bypass flow in the channels.



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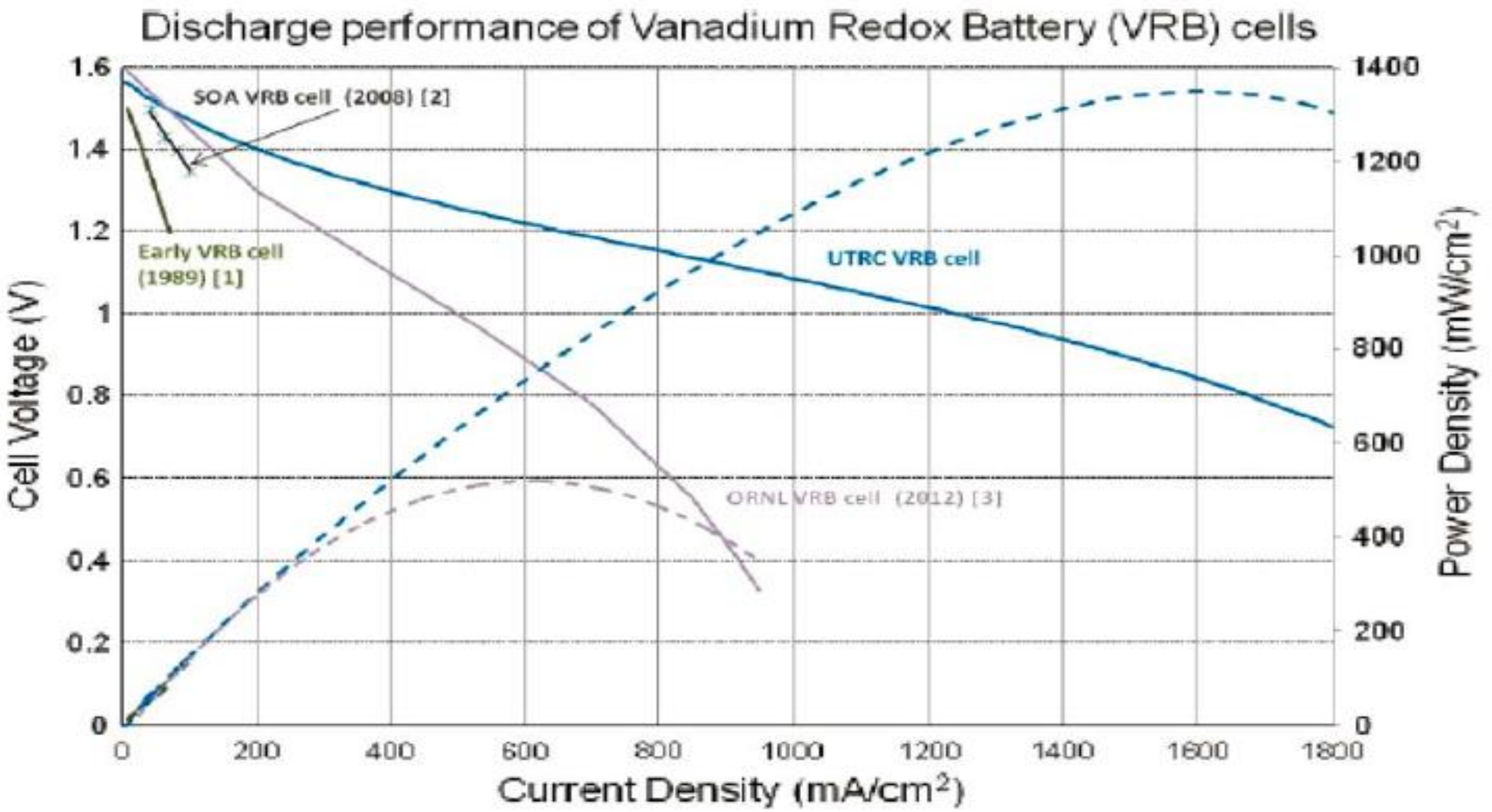
Demonstration of high current density operation of RFBs



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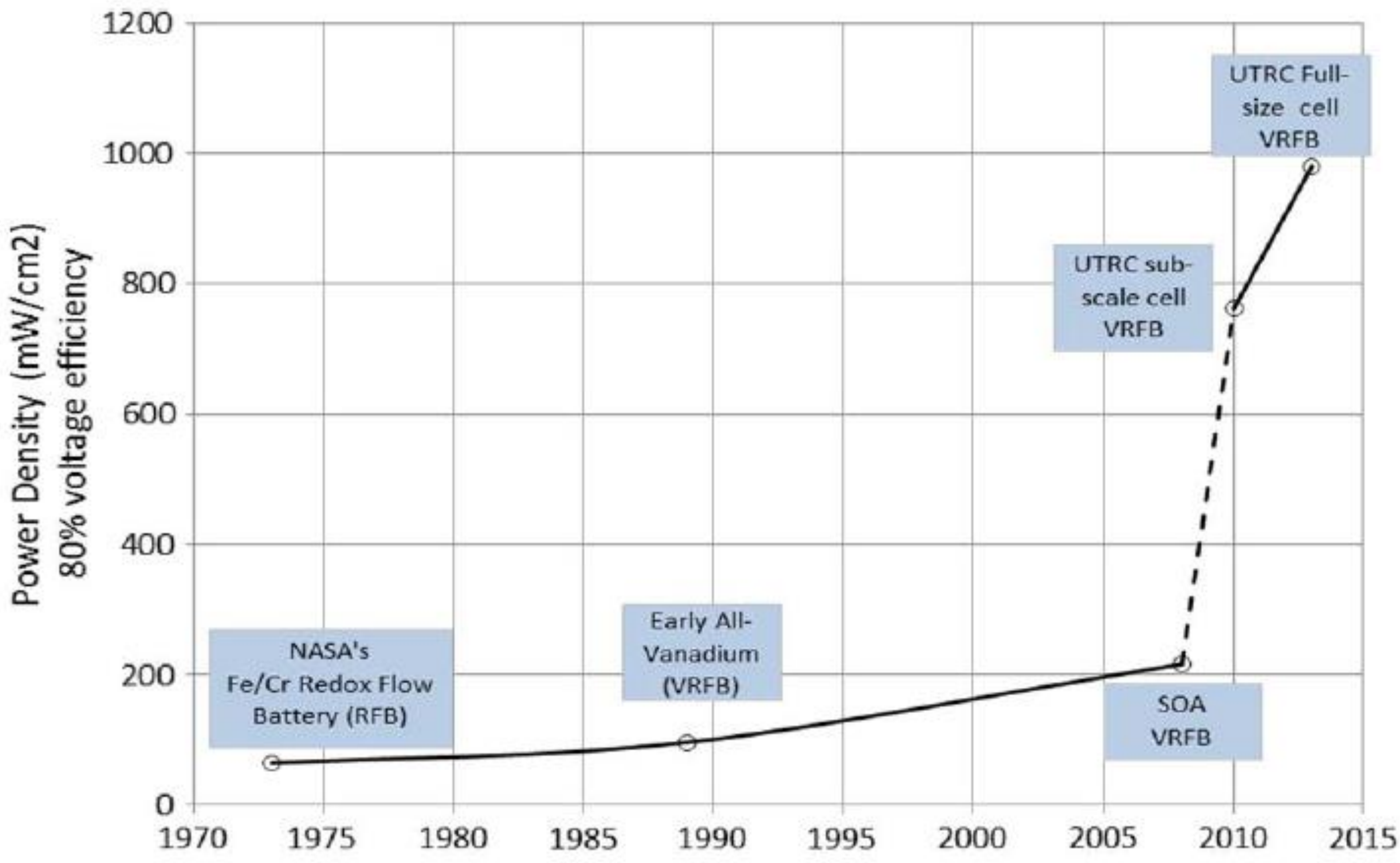
Historical perspective of recent cell performance improvements enabled by improvements in cell design and demonstrated by UTRC on large VRB cells 820 cm2 per cell in prototype RFB stacks



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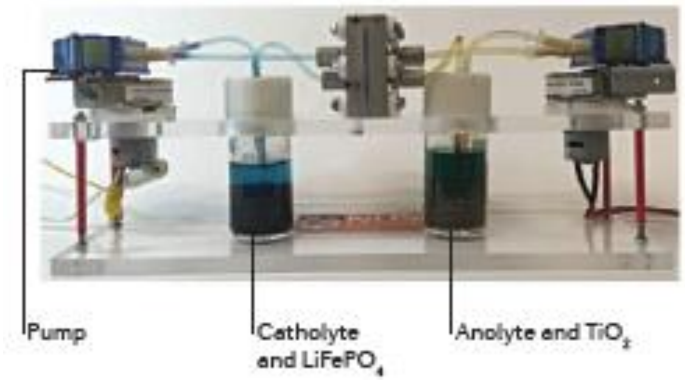
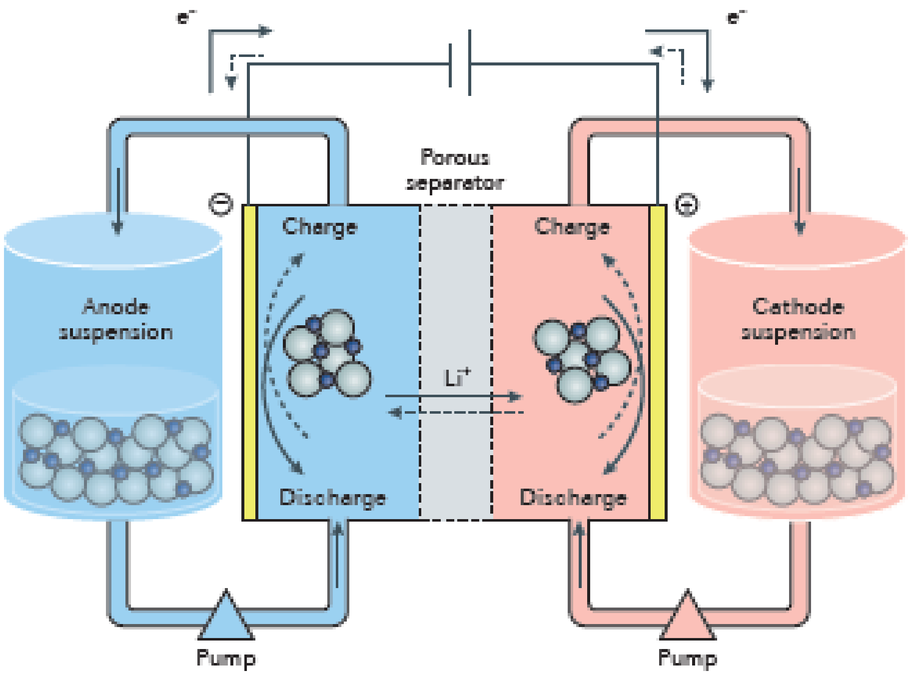
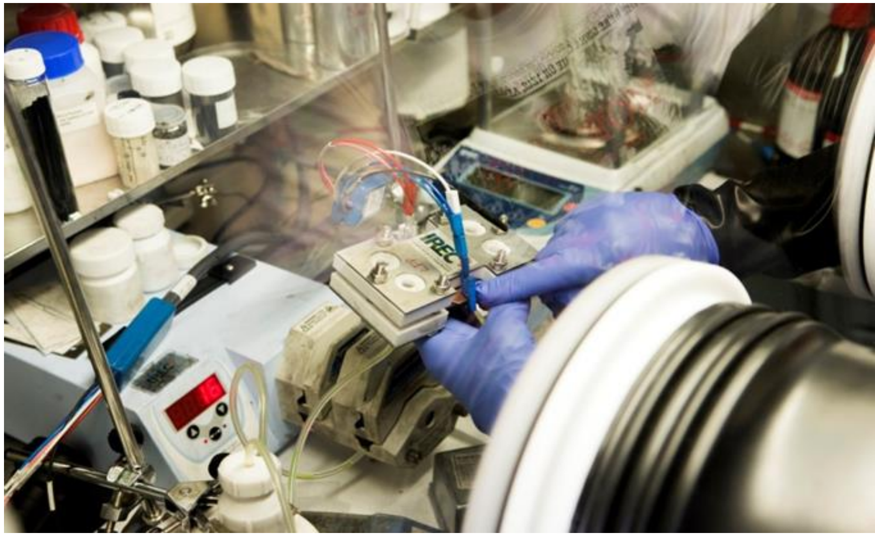
3 OTRAS BATERIAS DE FLUJO



24M (A123)





Semi-solid flow battery

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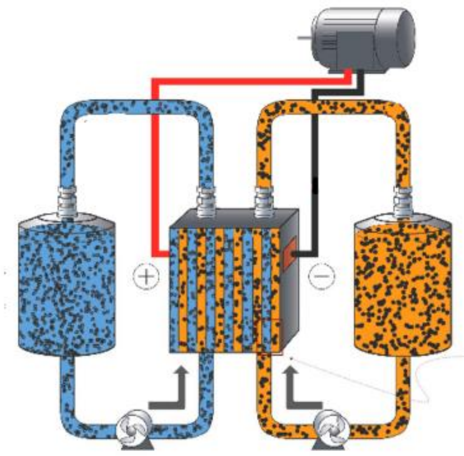
Advantages of Semi-solid Flow Batteries



✓ **Energy Densities can reach**

up to 100 -200 Wh L^{-1}

($Li_4Ti_5O_{12}$, $LiCoO_2$ or $LiNi_{0.5}Mn_{1.5}O_4$)

which is more than 10 times higher than that of all-vanadium RFBs (15-25 Wh L^{-1}).

Chemistry	Charge capacity / mAh g^{-1}	Cell voltage / V	Specific energy / Wh kg^{-1}	Energy density / Wh L^{-1}	Realistic energy density / Wh L^{-1}
$Li_4Ti_5O_{12}$ LiNMC	170 160	2,3	190 (105)	750 (250‡)	100*
Al LiNMC	1000 160	2,8	385 (190)	1590 (475‡)	190*
Si LiNMC	3500 160	3,6	550 (280)	2380 (715‡)	290*
ZnO NaNMC	660 140	2,0	230 (115)	1080 (325‡)	130*

‡ theoretical energy density for 30 vol% of active material in suspension
* energy density for 30 vol% of active material in suspension, reaching 50 % of the theoretical charge capacity, and achieving 80 % state of discharge.

positive or cathode: $6LiCoO_2 \leftrightarrow 6Li_{\sim0.5}CoO_2 + 3Li^+ + 3e^-$
negative or anode: $Li_4Ti_5O_{12} + 3Li^+ + 3e^- \leftrightarrow Li_7Ti_5O_{12}$
Total: $6LiCoO_2 + Li_4Ti_5O_{12} \leftrightarrow 6Li_{\sim0.5}CoO_2 + Li_7Ti_5O_{12}$

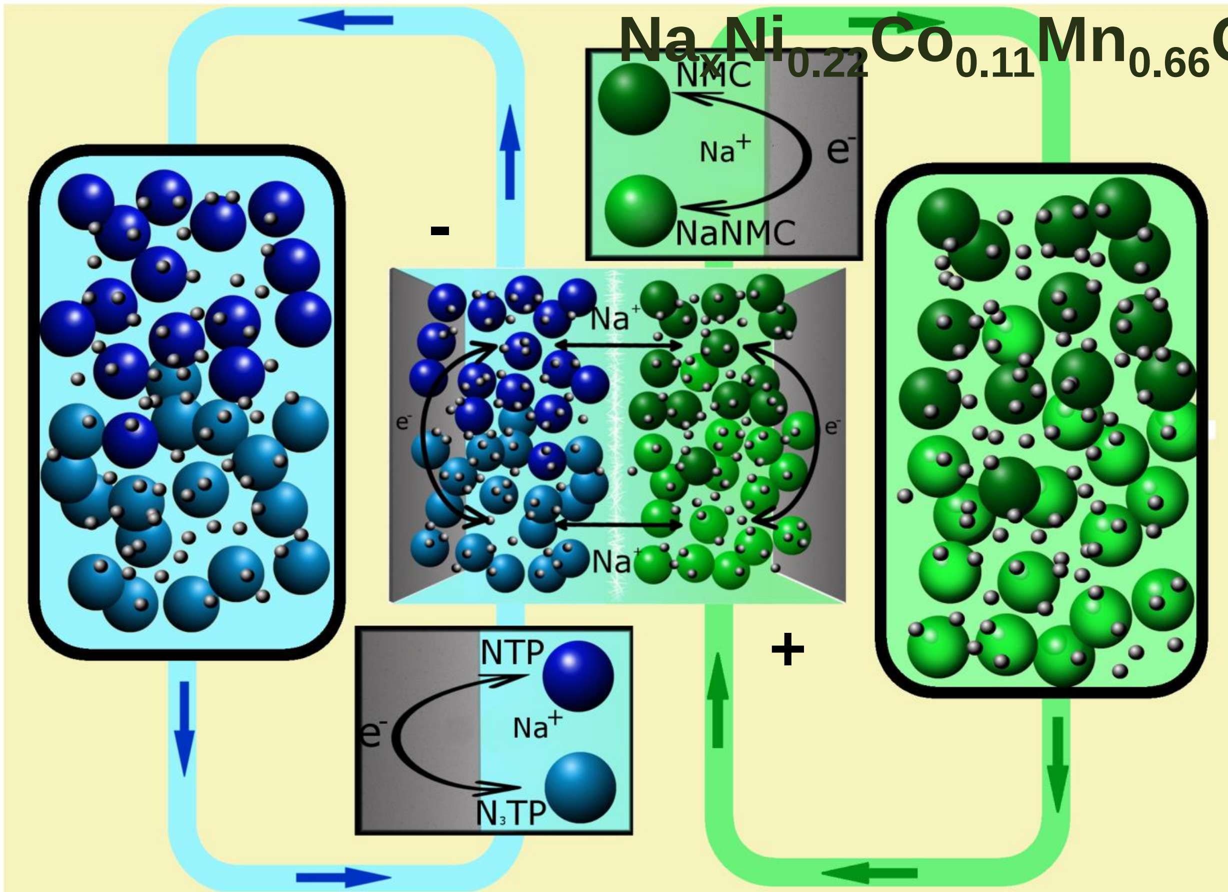
PROOF-OF CONCEPT of SODIUM-ION SSFB

- ✓ **Abundant, Inexpensive**
- ✓ **Energy densities of *ca.* 200 Wh kg**

P2-type

$Na_xNi_{0.22}Co_{0.11}Mn_{0.66}O_2$

$NaTP + 2\,Na^+ + 2\,e^- \longleftrightarrow Na_3TP$



$NaxNMC \longleftrightarrow NMC + X\,Na^+ + Xe^-$

$NaTi_2(PO_4)_3$

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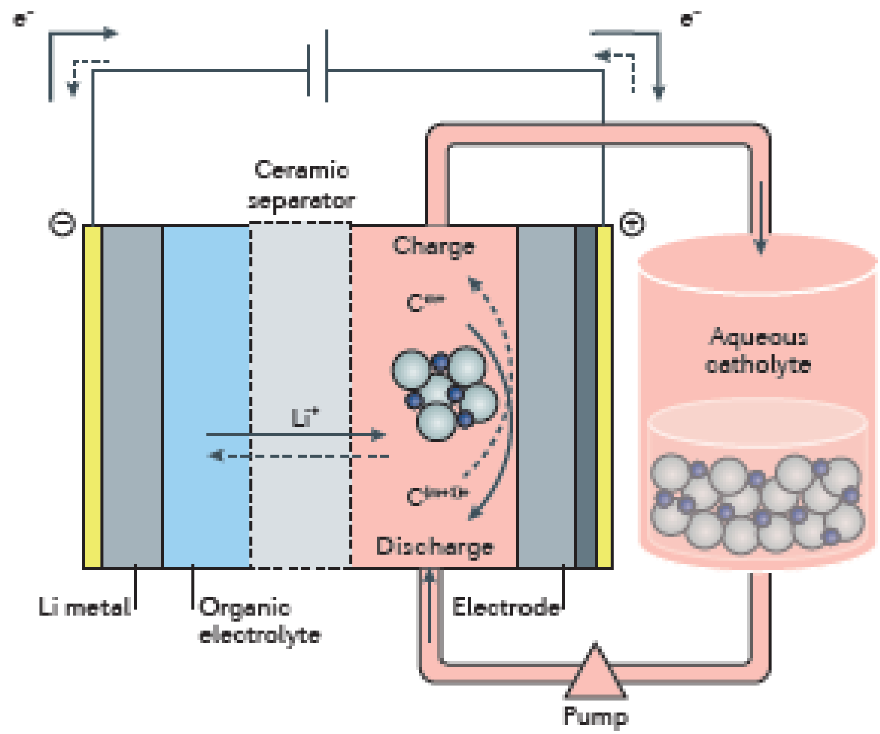
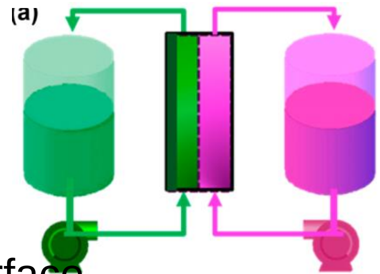
Li-metal based flow battery

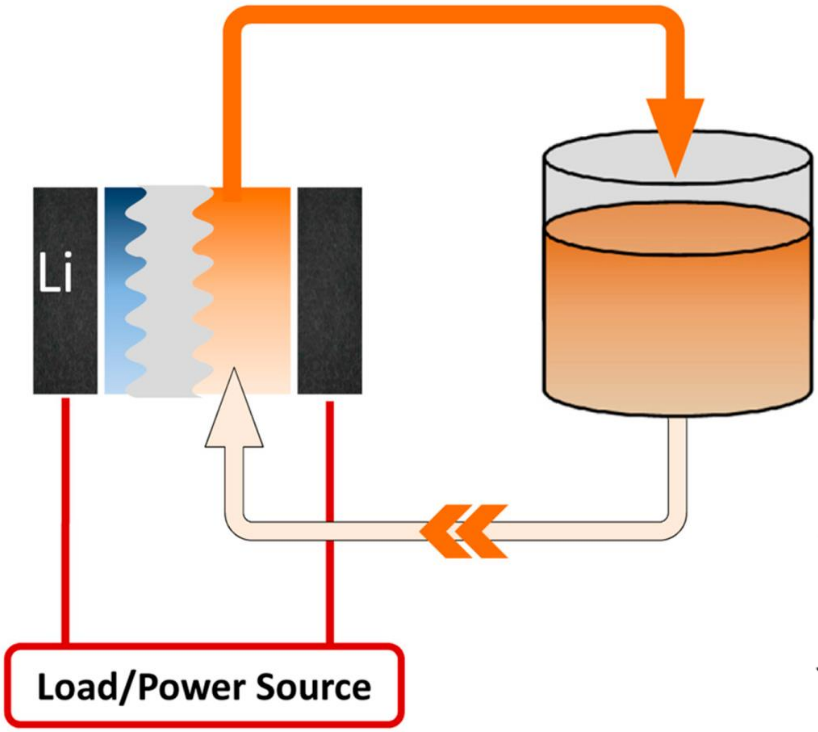


supplying fresh electrolyte onto the metal anode

Flow batteries with anode metal

Lithium-ion flow batteries





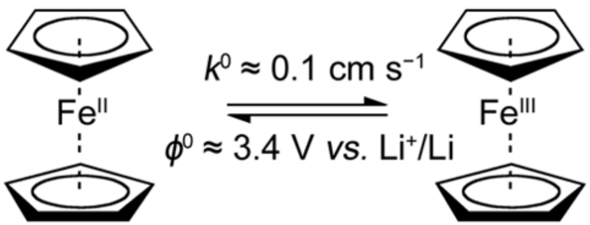
Characteristics

-Dendrite formation on surface of Lithium metal

-Early stage of development

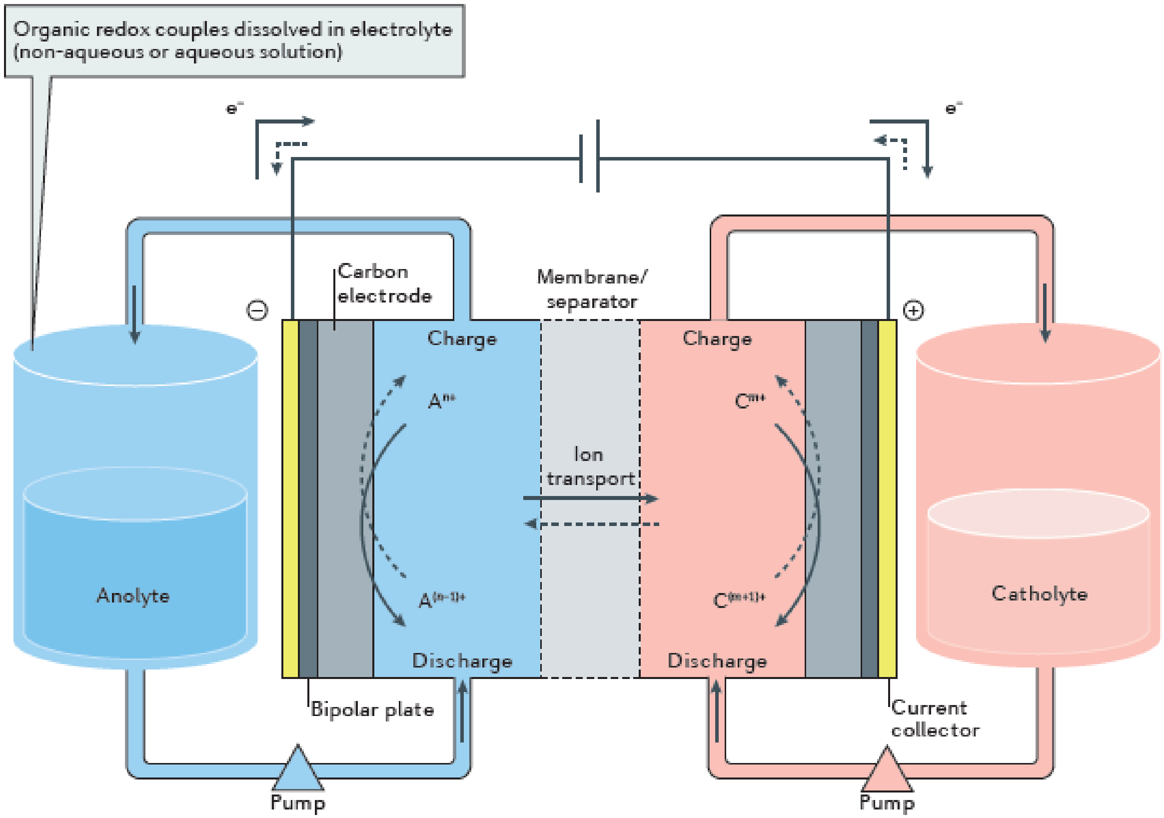
-Fe^{2+}/Fe^{3+} 3.40 V

-Fc/Fc^{+} 40 Wh L^{-1}

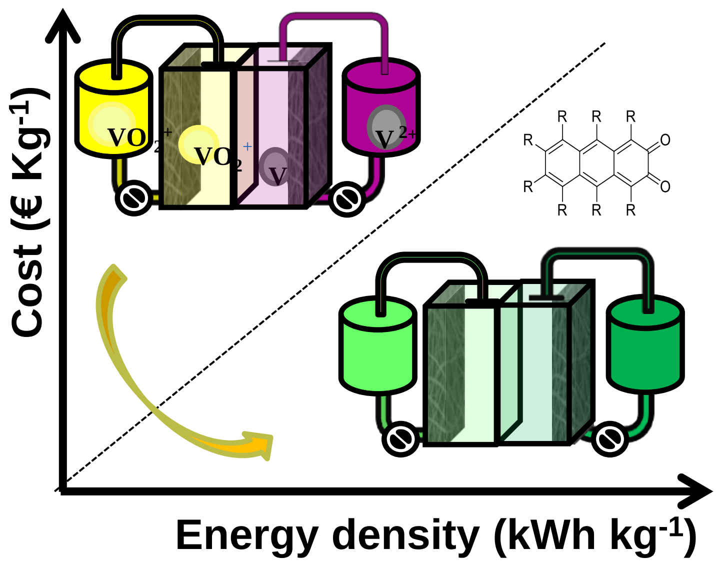


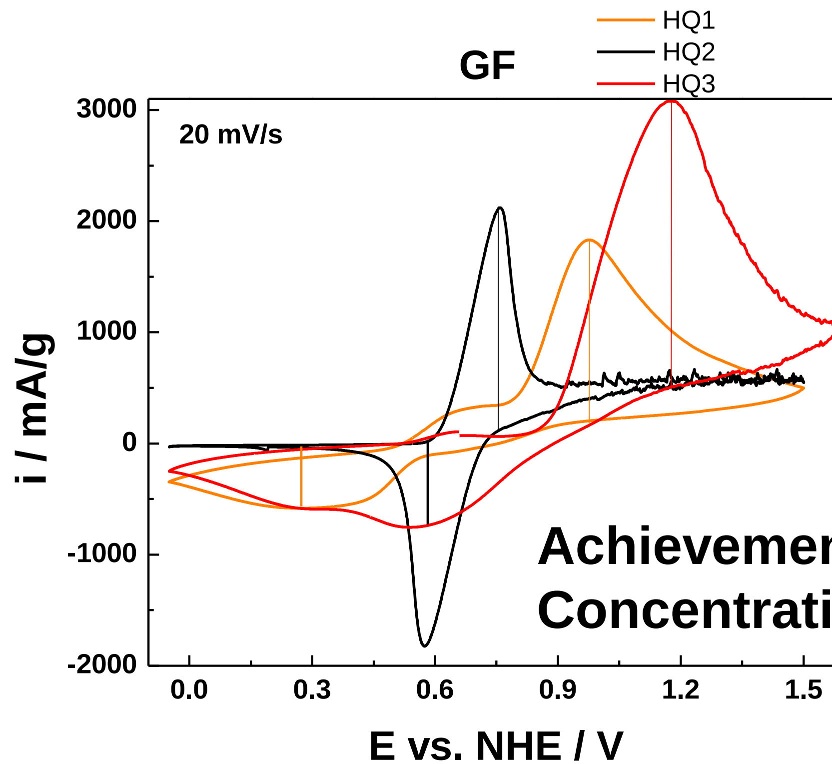
side	Redox process	E_{red}°ocv/V (vs SHE)
+	$M^+ + e^- \leftrightarrows M_{(aq)}$	
-	$Li - e^- \leftrightarrows Li^+$	3.04

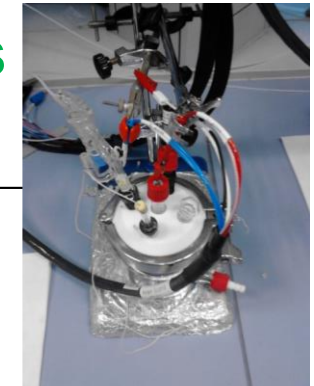
All-organic redox-flow battery



Organic flow batteries in aqueous





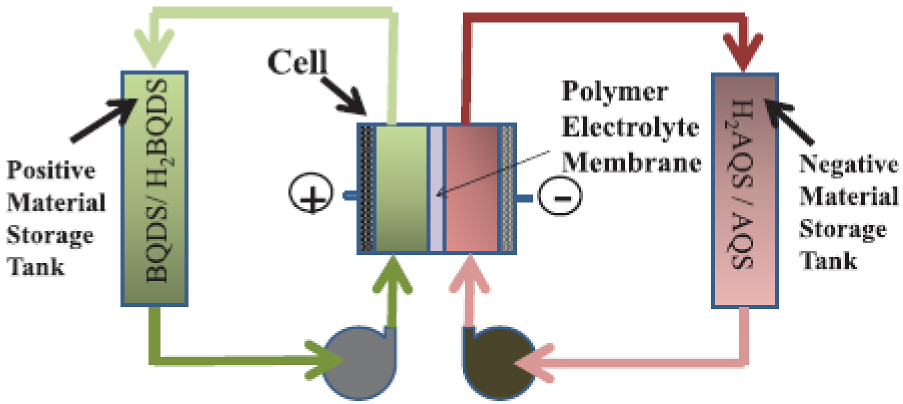


Achievement:
Concentration of 3 M

Fundación Ramon Areces " 17th National Competition "Grants for Research in Life Sciences and Matter" for the category "Renewable Energy: Materials and Processes ". This award will be used to carry out a research project entitled "Metal-free Redox Flow Batteries for renewable energy integration- BAT-LIMET". The project will focus on the development and application of high energy density redox flow battery with the implementation of green and cost-effective electrolytes.

All-liquid flow batteries

Organic flow batteries



Features

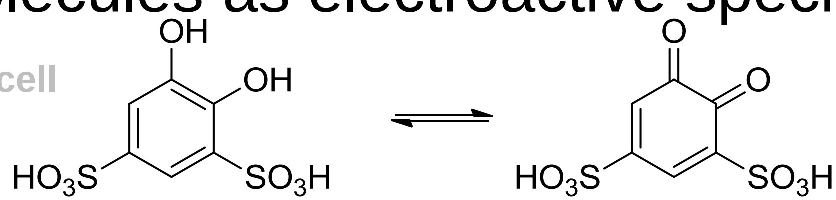
- Organic electroactive species dissolved in the electrolyte
-Energy efficiency: 82%
- Energy density: 1.4 WhL^{-1}

Cost $10-20/kWh

Cell Voltage 1.0 V

Organic molecules as electroactive species in aqueous electrolyte

Positive semi-cell reaction:

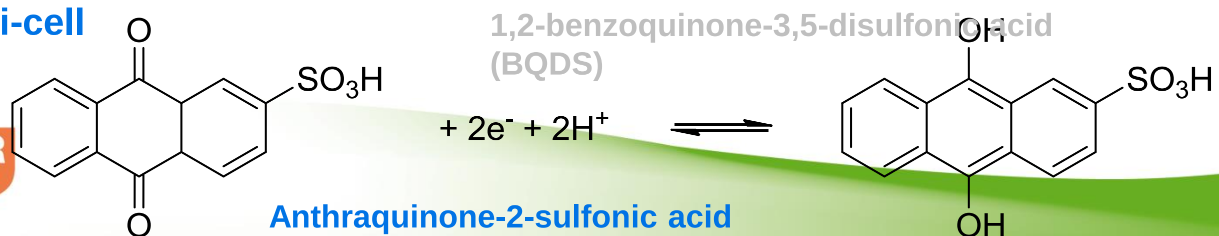


$+ 2e^- + 2H^+$

$E^0 = 0.85$ V

1,2-benzoquinone-3,5-disulfonic acid (BQDS)

Negative semi-cell reaction:



Anthraquinone-2-sulfonic acid (AQS)

$E^0 = 0.09$ V

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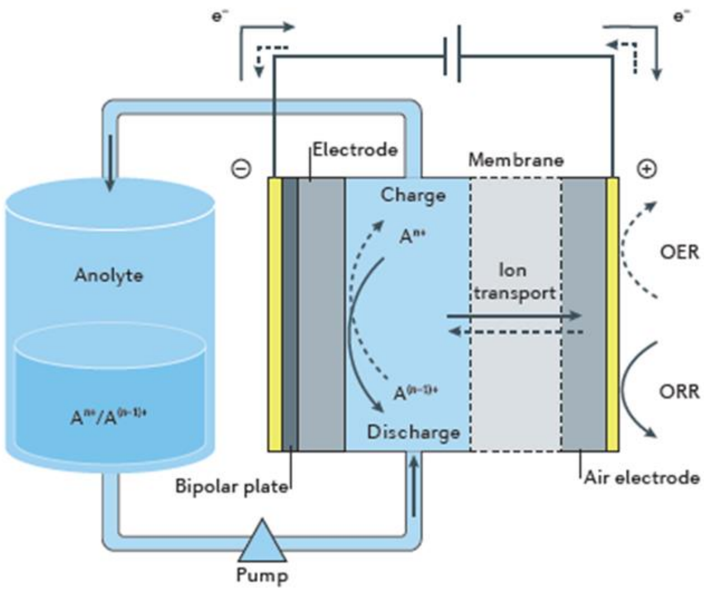
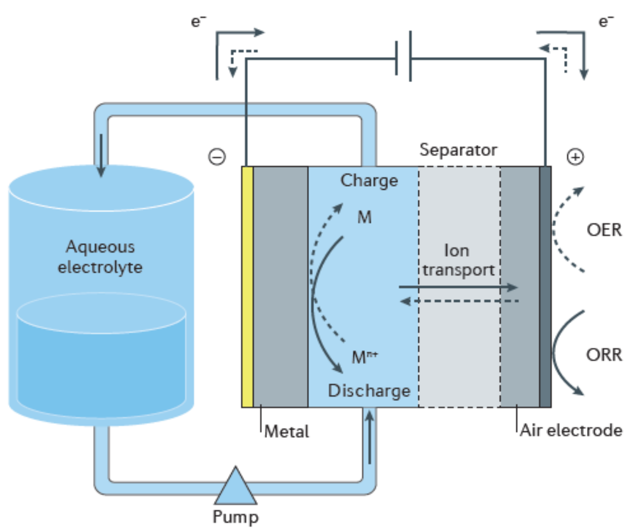
Metal–air flow batteries



Circulating the anolyt



supplying fresh
electrolyte
onto the metal anode

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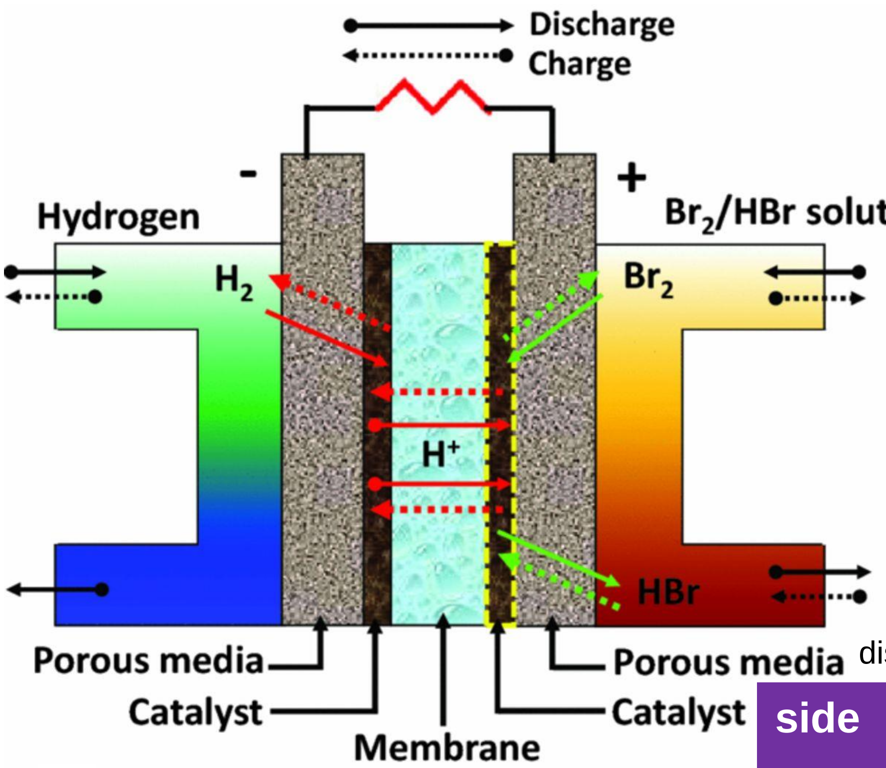
METAL AIR.

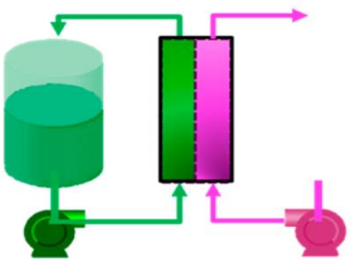
http://www.phinergy.com/
http://www.israelscienceinfo.com/en/hightech/phinergy-israel-voiture-roule-lair-grace-batteries-metal-air/
http://www.newslexpoint.com/israel-made-car-runs-metals-air-water/

Flow batteries with gas electrode:

Hydrogen-anode flow batteries



discharged catholyte



Characteristics

- hybrid system of fuel cell + flow battery

- highly reversible behaviour

- fast kinetics for both redox processes

-Crossover over membrane and poisoning of Pt catalyst with bromide

side	Redox process	E_{red}°ocv/V (vs SHE)
+	$Br_{2(aq)} + 2e \leftrightarrows 2Br^-_{(aq)}$	1.10
-	$H_{2(g)} \leftrightarrows 2H^+ + 2e$	0.00
		Cell voltage: 1.10V

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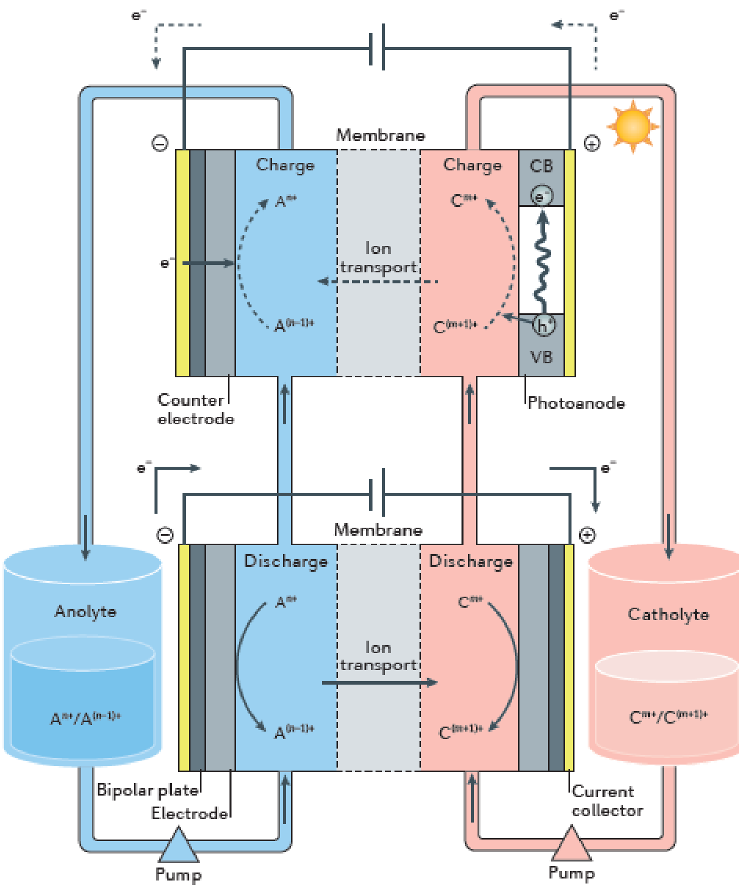
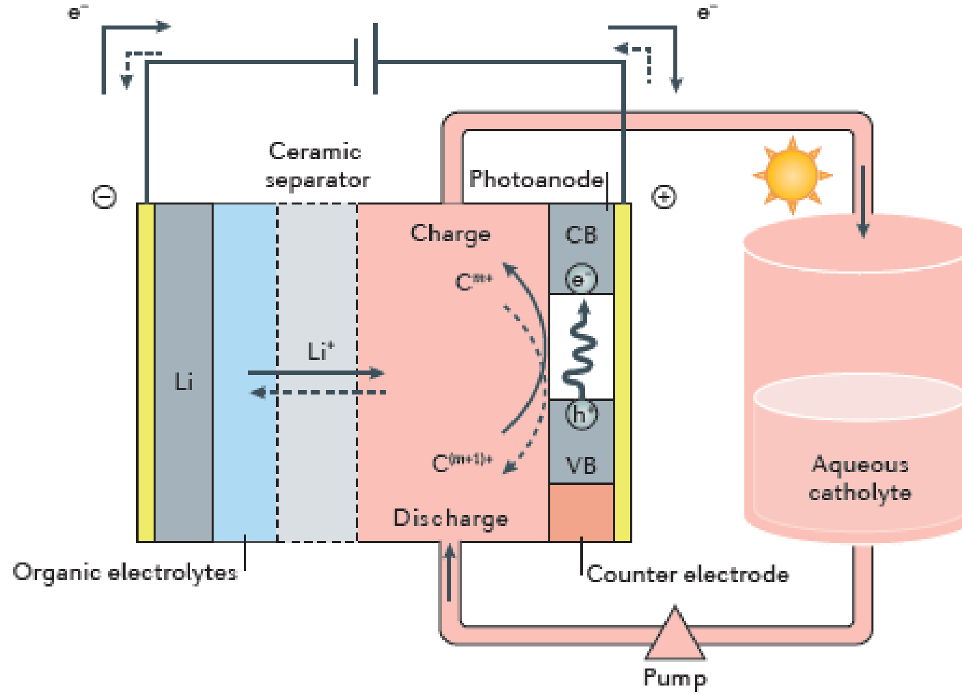
Solar rechargeable flow batteries, SRFB





Lithium-based solar rechargeable flow battery (SRFB)

A SRFB combined with a photoelectrochemical (PEC) cell for solar charging of electrolytes and with a RFB for electrochemical discharge

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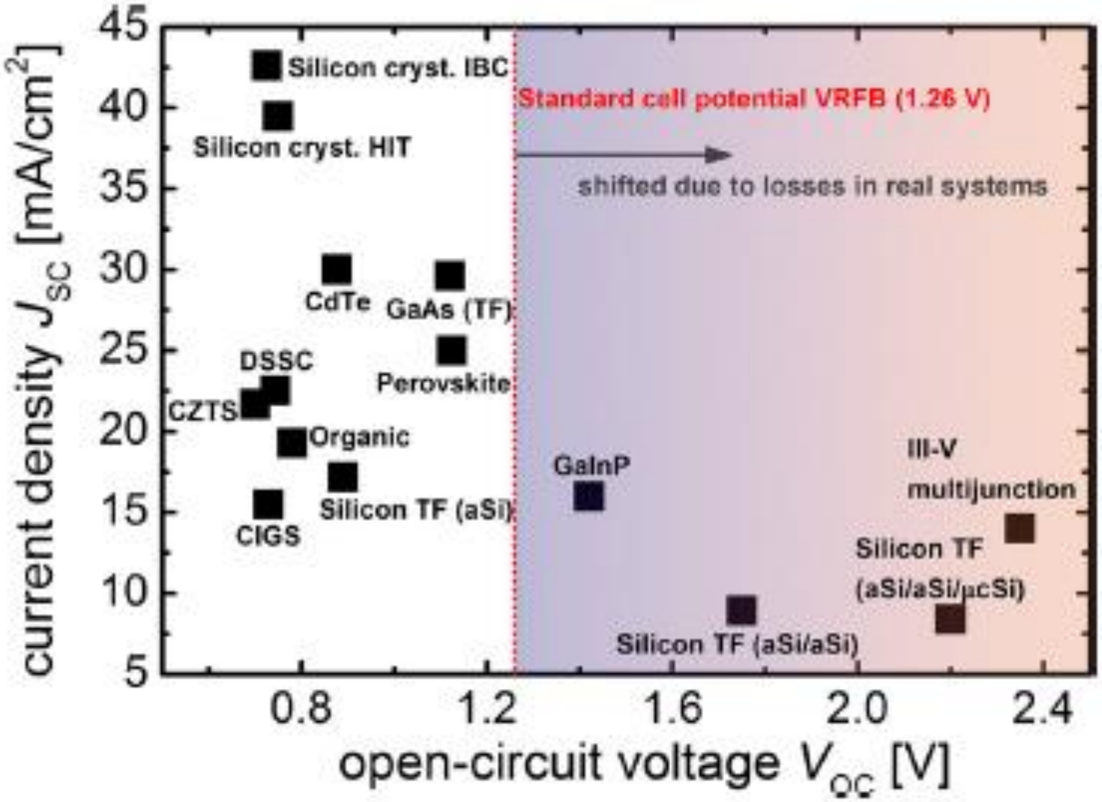

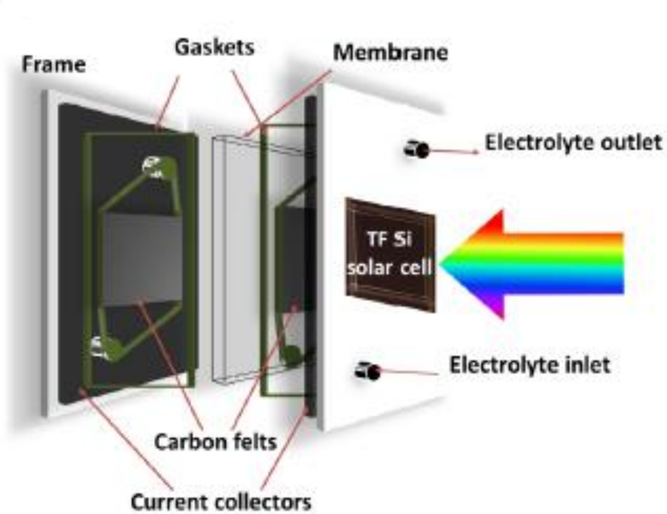

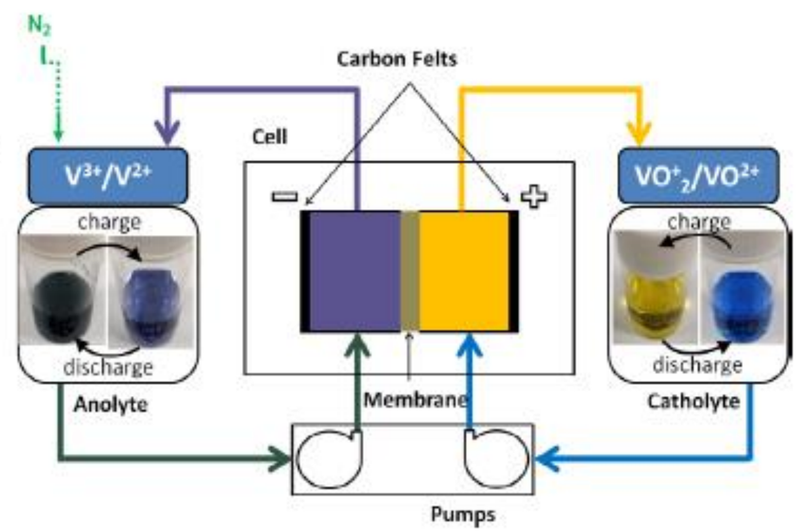

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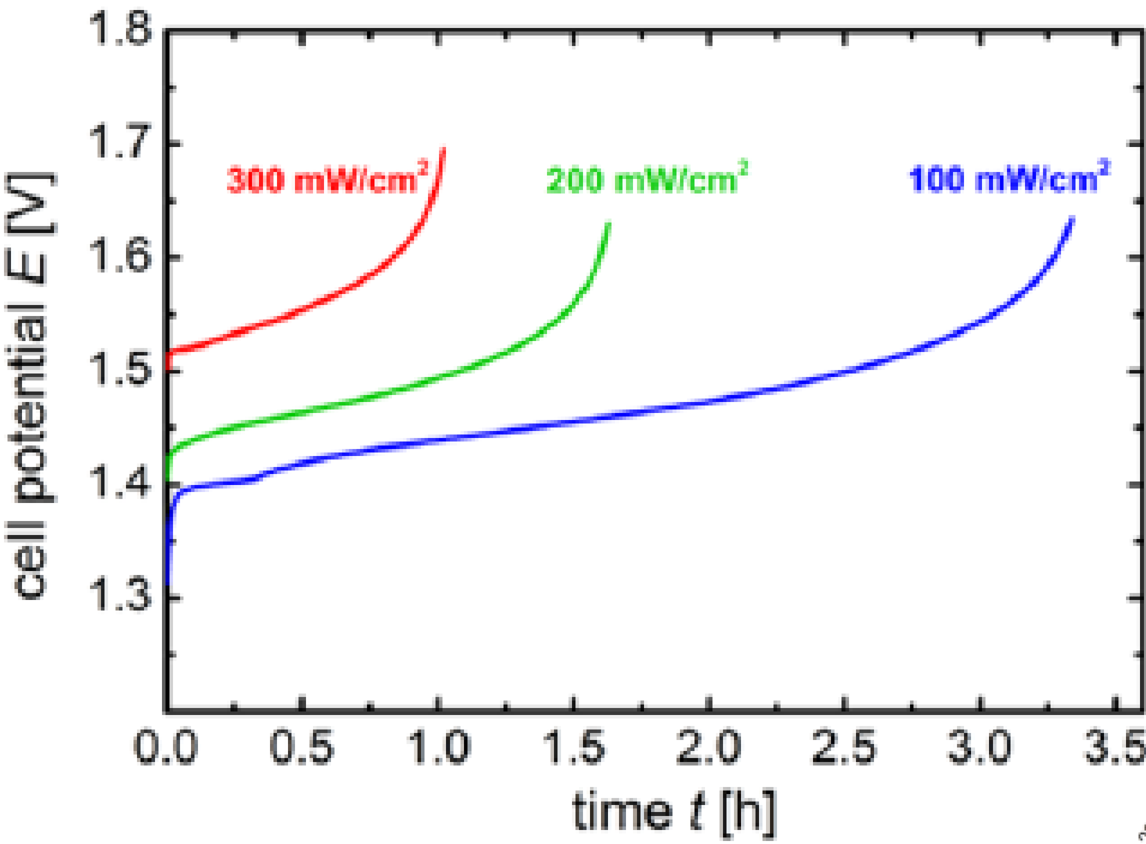

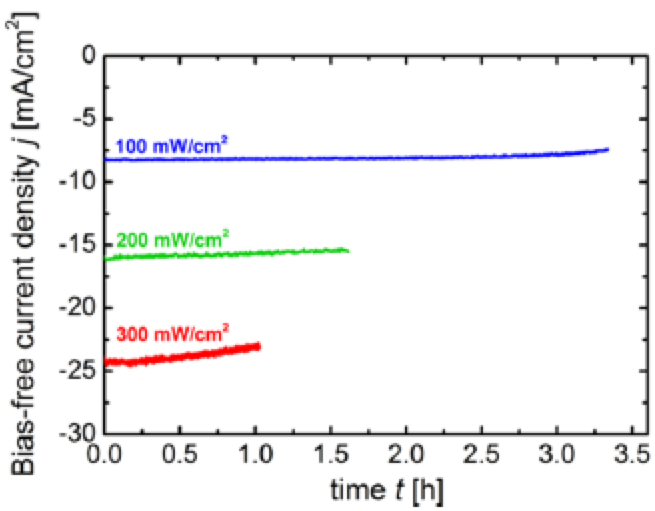

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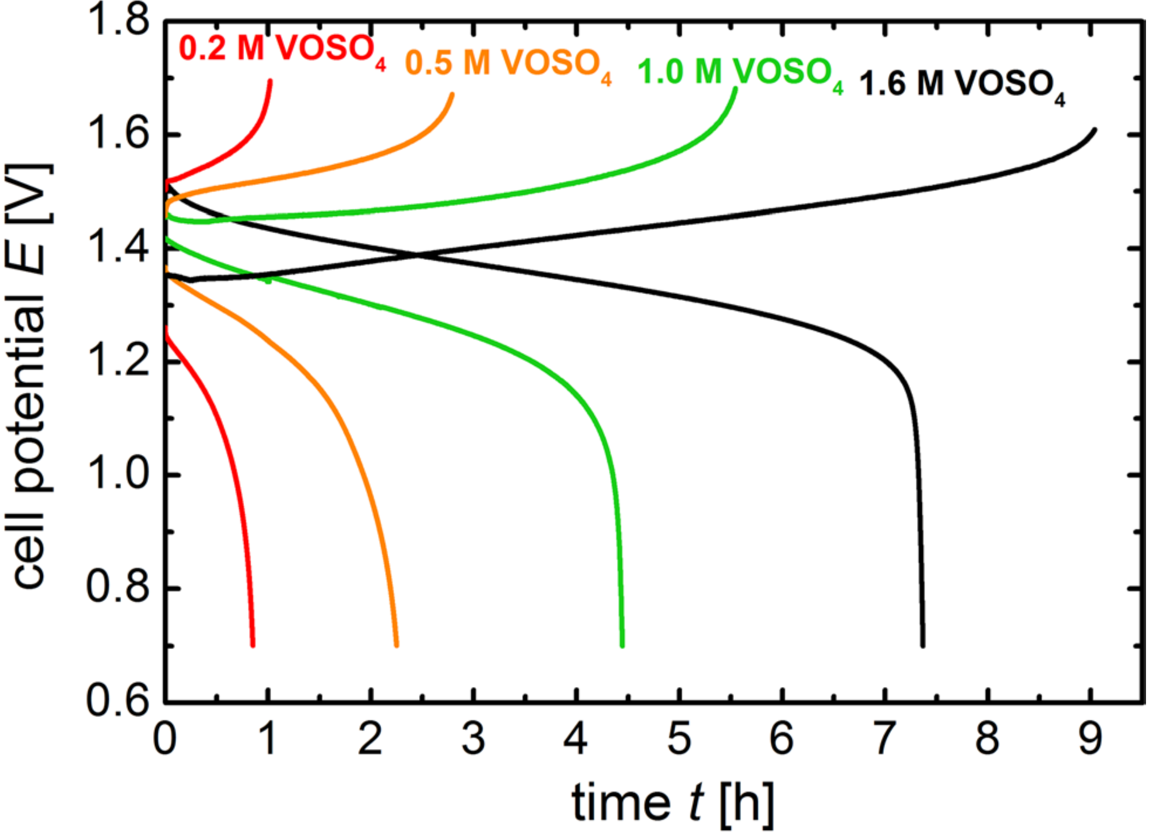
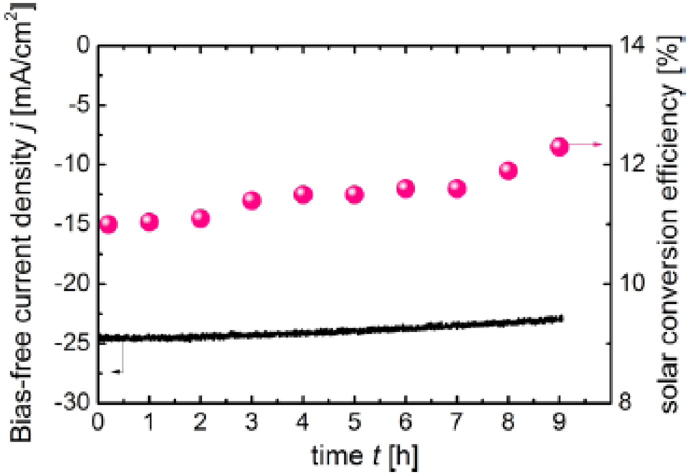


Charge–discharge performance of the solar VRFB as a function of the vanadium concentration. The illumination intensity was 300 mW cm−2 for all investigated devices along with an average charging photocurrent density of 23.5 mA cm−2, which was also applied for the discharge processes. The electrolyte flow rate was kept constant at 35 ml min−1



Solar conversion efficiency over the charging time based on the bias-free charging current and the complete VRFB cell potential plotted for the 1.6 M vanadium solution.

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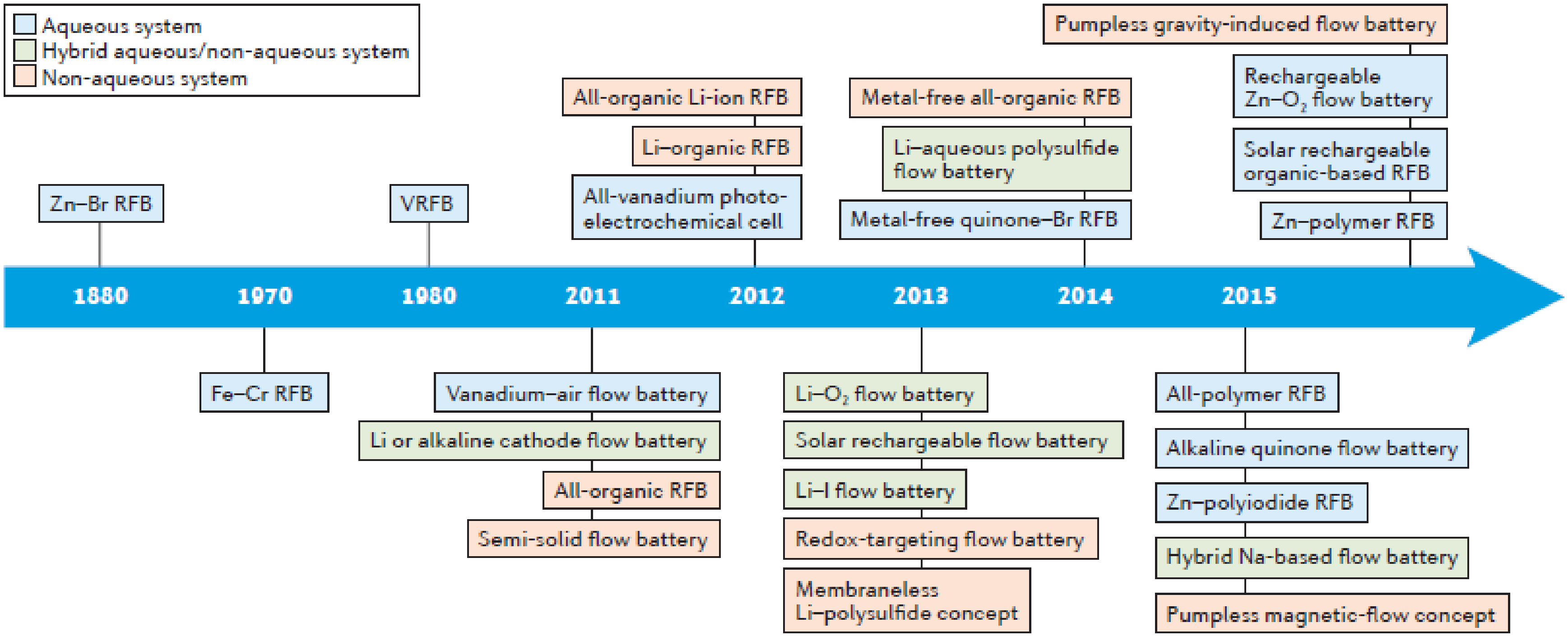
Aqueous system
Hybrid aqueous/non-aqueous system
Non-aqueous system
Zn–Br RFB
VRFB
All-organic Li-ion RFB
Li–organic RFB
All-vanadium photo-electrochemical cell
Metal-free all-organic RFB
Li–aqueous polysulfide flow battery
Metal-free quinone–Br RFB
Pumpless gravity-induced flow battery
Rechargeable $Zn–O_2$ flow battery
Solar rechargeable organic-based RFB
Zn–polymer RFB
1880
1970
1980
2011
2012
2013
2014
2015
Fe–Cr RFB
Vanadium–air flow battery
Li or alkaline cathode flow battery
All-organic RFB
Semi-solid flow battery
$Li–O_2$ flow battery
Solar rechargeable flow battery
Li–I flow battery
Redox-targeting flow battery
Membraneless Li–polysulfide concept
All-polymer RFB
Alkaline quinone flow battery
Zn–polyiodide RFB
Hybrid Na-based flow battery
Pumpless magnetic-flow concept

Benefits of Li-Ion and Flow Bat. vs. Lead acid

- Excellent cycle life → 3 times more (1500 for Lead vs. 4500 for Li-Ion)
  - **Flow batteries have 3 times more than Li-ion**
- Very high roundtrip efficiency → 95% for Li-Ion vs. 80% for Lead (without considering consumption for ambient conditions maintenance up to 20%)
  - **Flow batteries have 80% at high current densities.**
- High power capability → required for complex residential load profiles
  - **Flow batteries have easy management**
- Maintenance free → No need of refill etc.
- Footprint and weight is 5 times smaller for Li-Ion
  - **Today Flow batteries have worst footprint**
- Usable energy (kWh) is limited to 50% for Lead vs. 90% for Li-Ion
  - **Flow bat's do not have limitations ~95%**

Ratio of energy throughput Lead/Li-Ion = $\frac{1500}{4500} \times \frac{0.8}{0.95} \times \frac{0.5}{0.9} = 0.156$

Ratio Li-ion/FRB = $\frac{4500}{15000} \times \frac{0.80*}{0.70*} \times \frac{0.9}{0.95} = 0.325$

More than 6 times energy throughput for Li-Ion during service life, when price is only about 4 times higher. More than 3 times FRB vs. Li-Ion and price is lower!.

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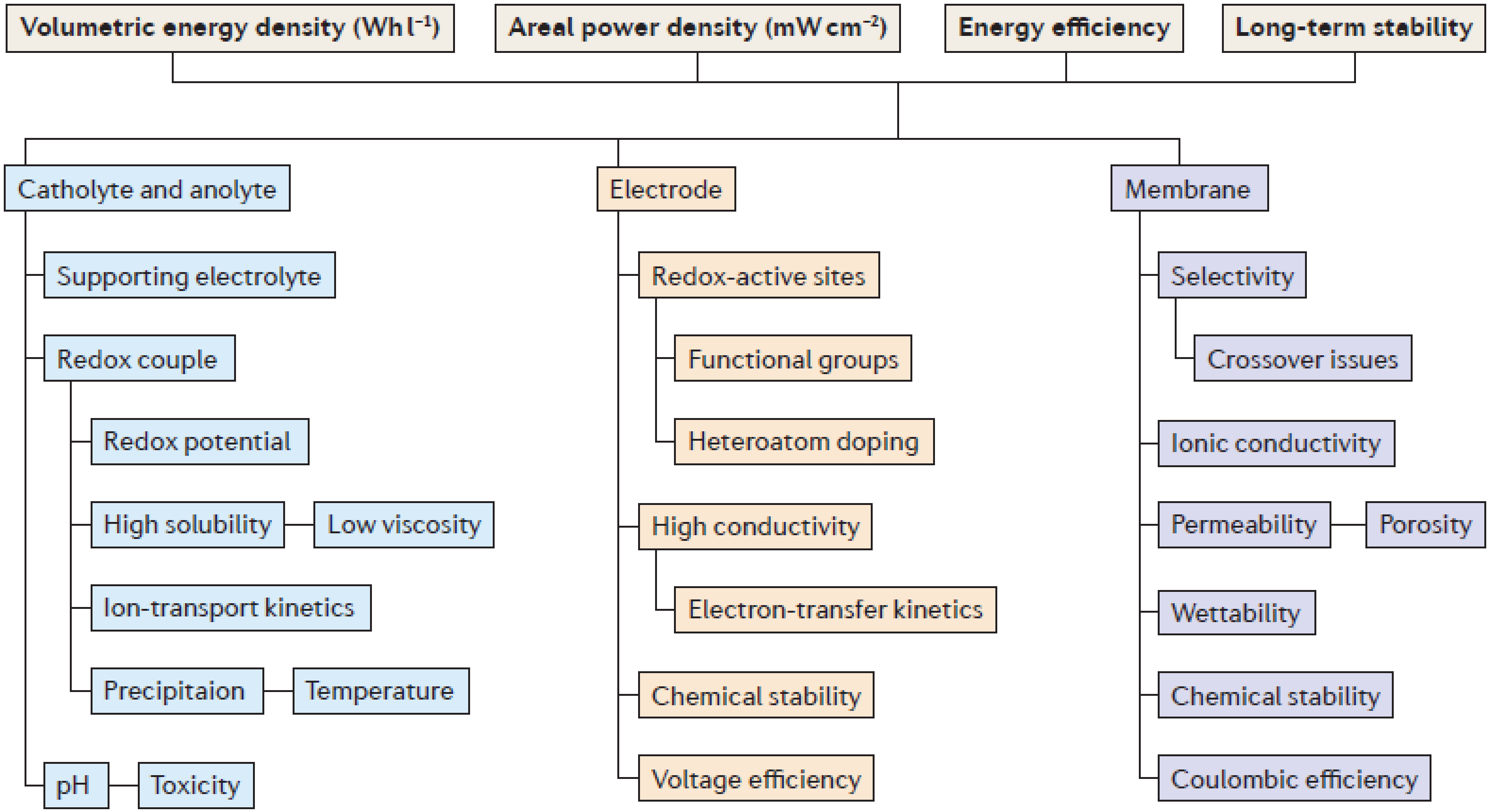
4 DESARROLLO TECNOLOGICO Y APLICACIONES.

Requirements and considerations for the development of flow batteries



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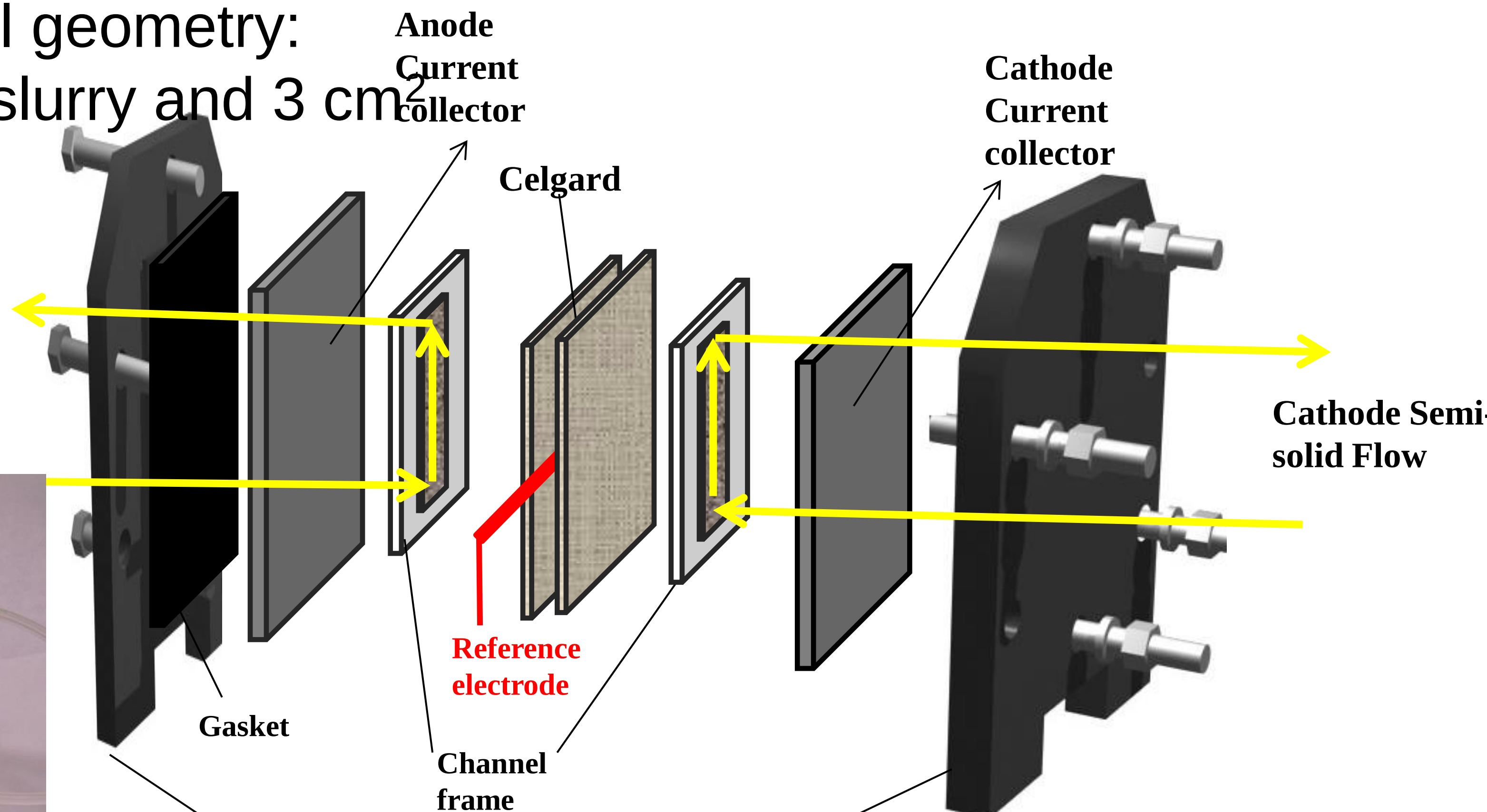
Test: Scheme of components integrating the full-cell filter press stack. The slurry flow through the cell is representing with yellow arrows

Channel geometry:
0.3 mL slurry and 3 cm^2



Elastomeric gaskets (not depicted here) will be used for preventing leaks between rigid parts

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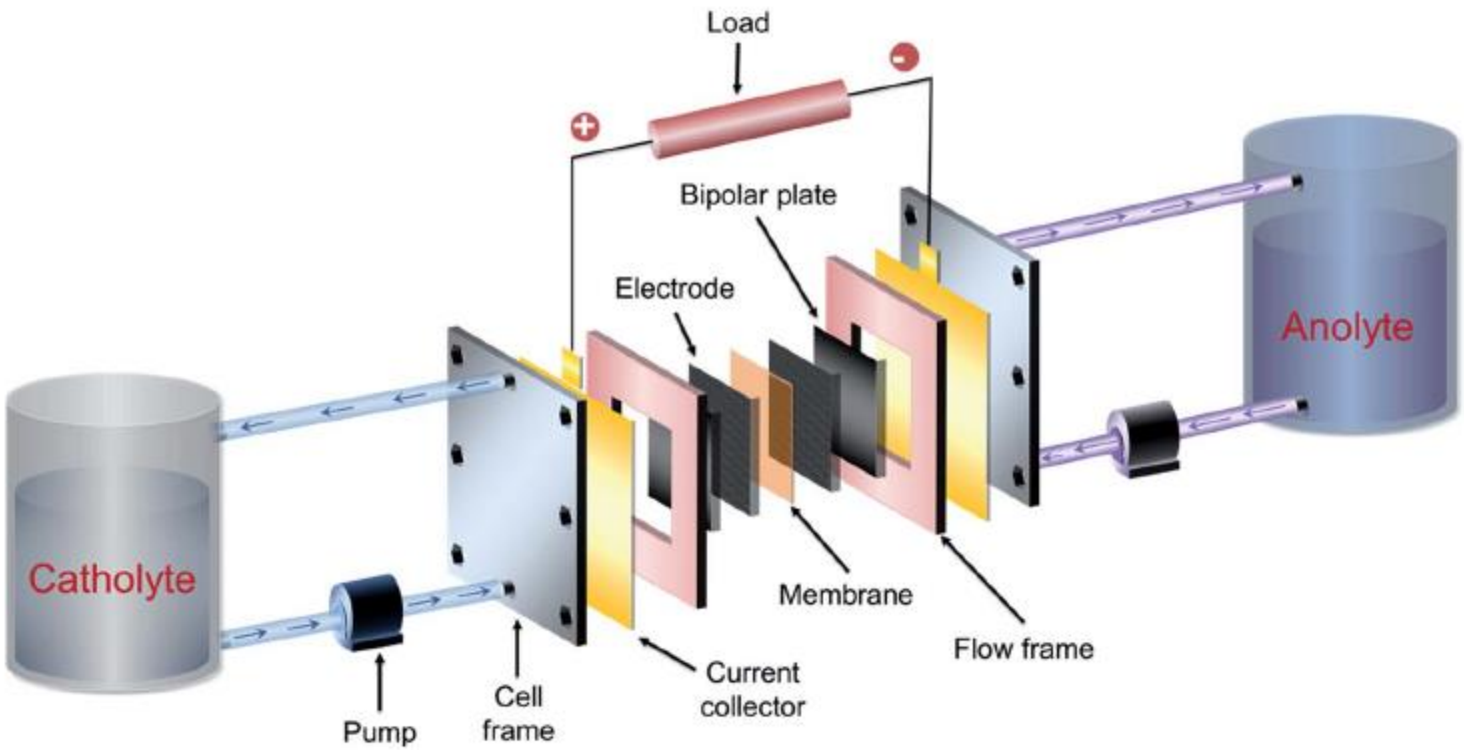
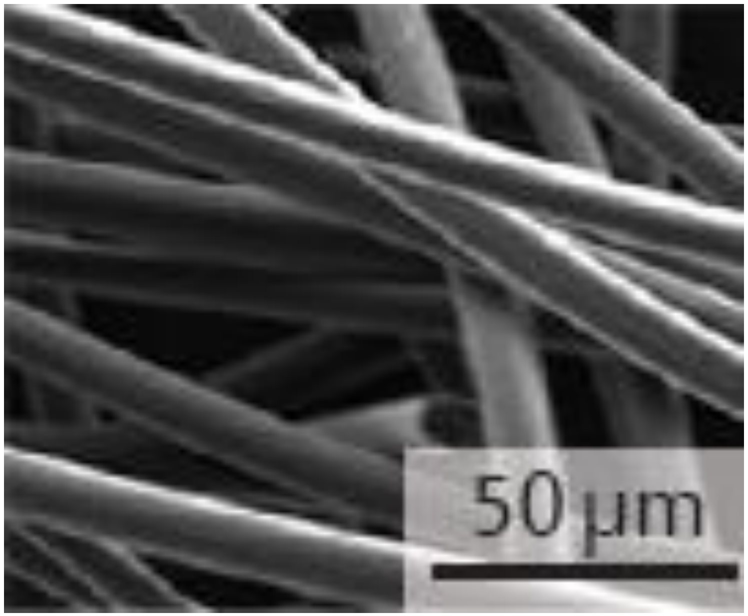
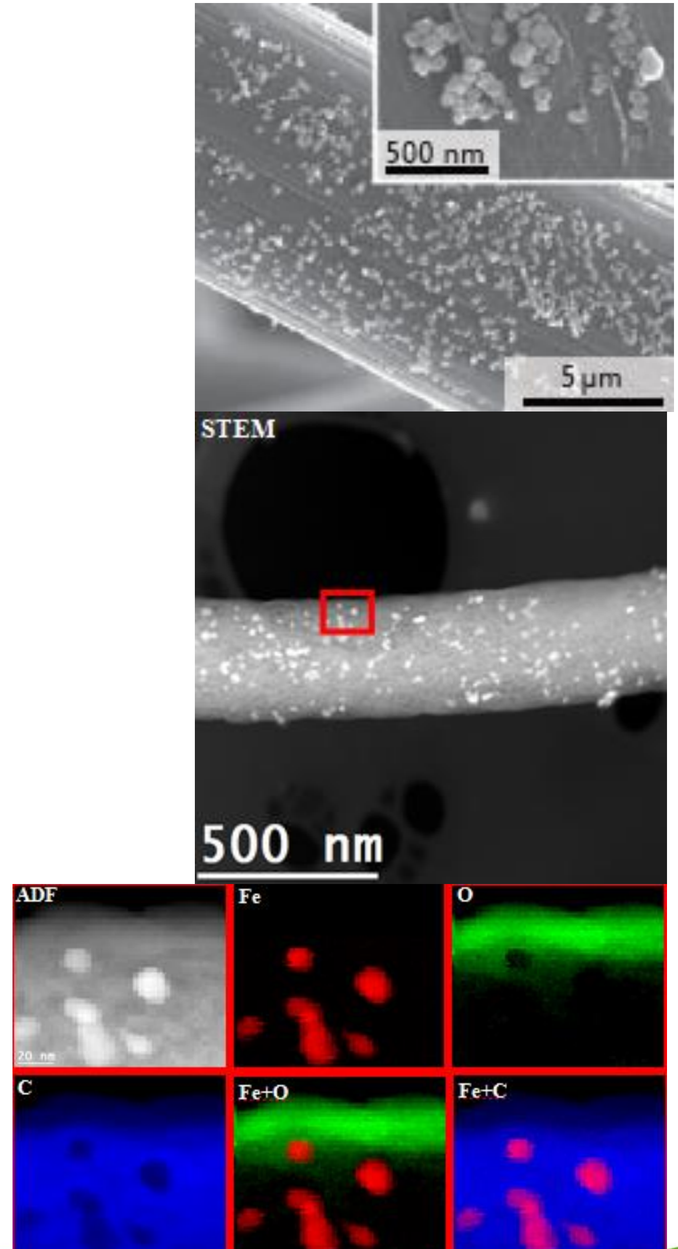

Load
Bipolar plate
Electrode
Anolyte
Catholyte
Membrane
Flow frame
Current
collector
Pump
Cell
frame

Electrode materials

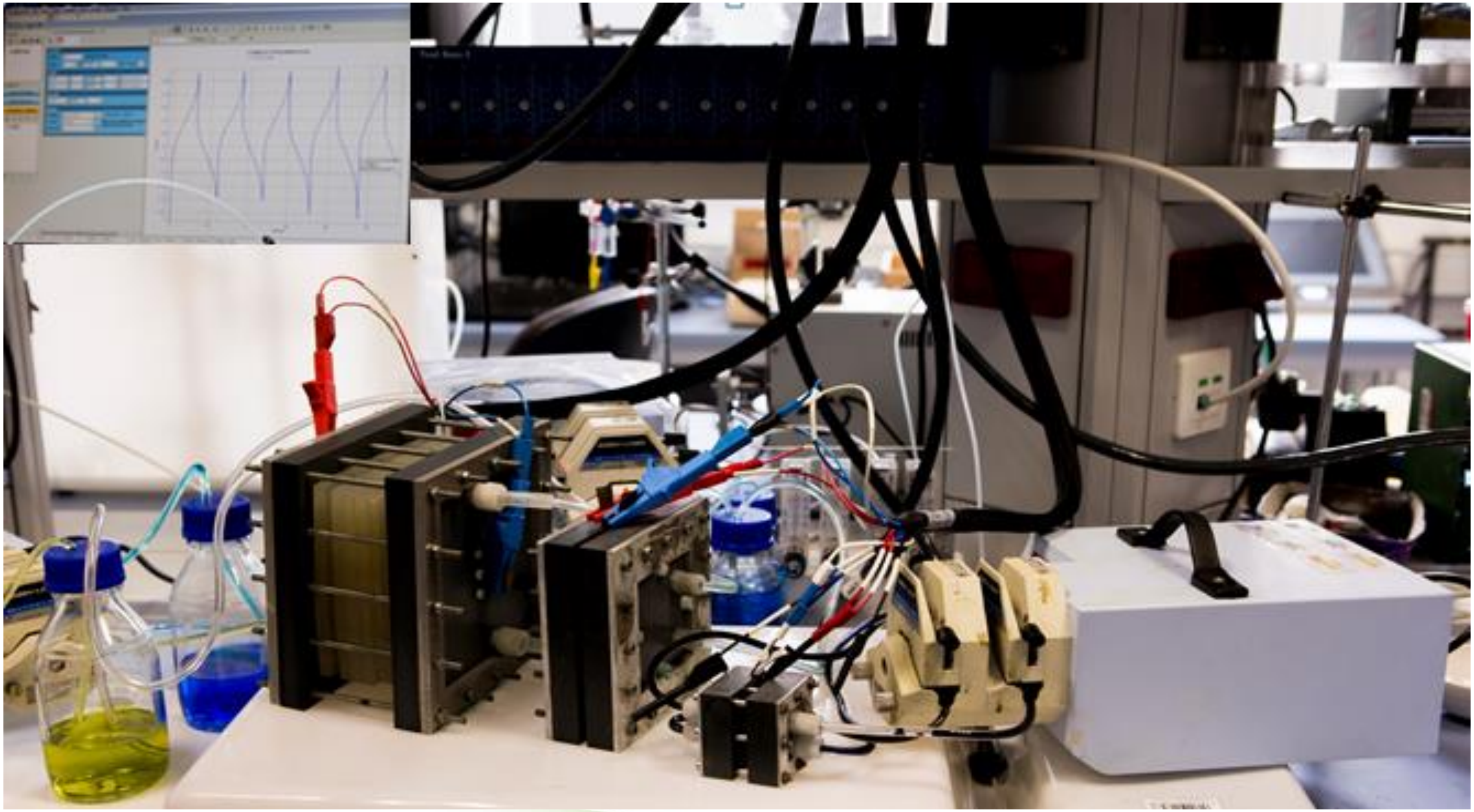


Pristine carbon felt



Modified with catalysts

Scale-up



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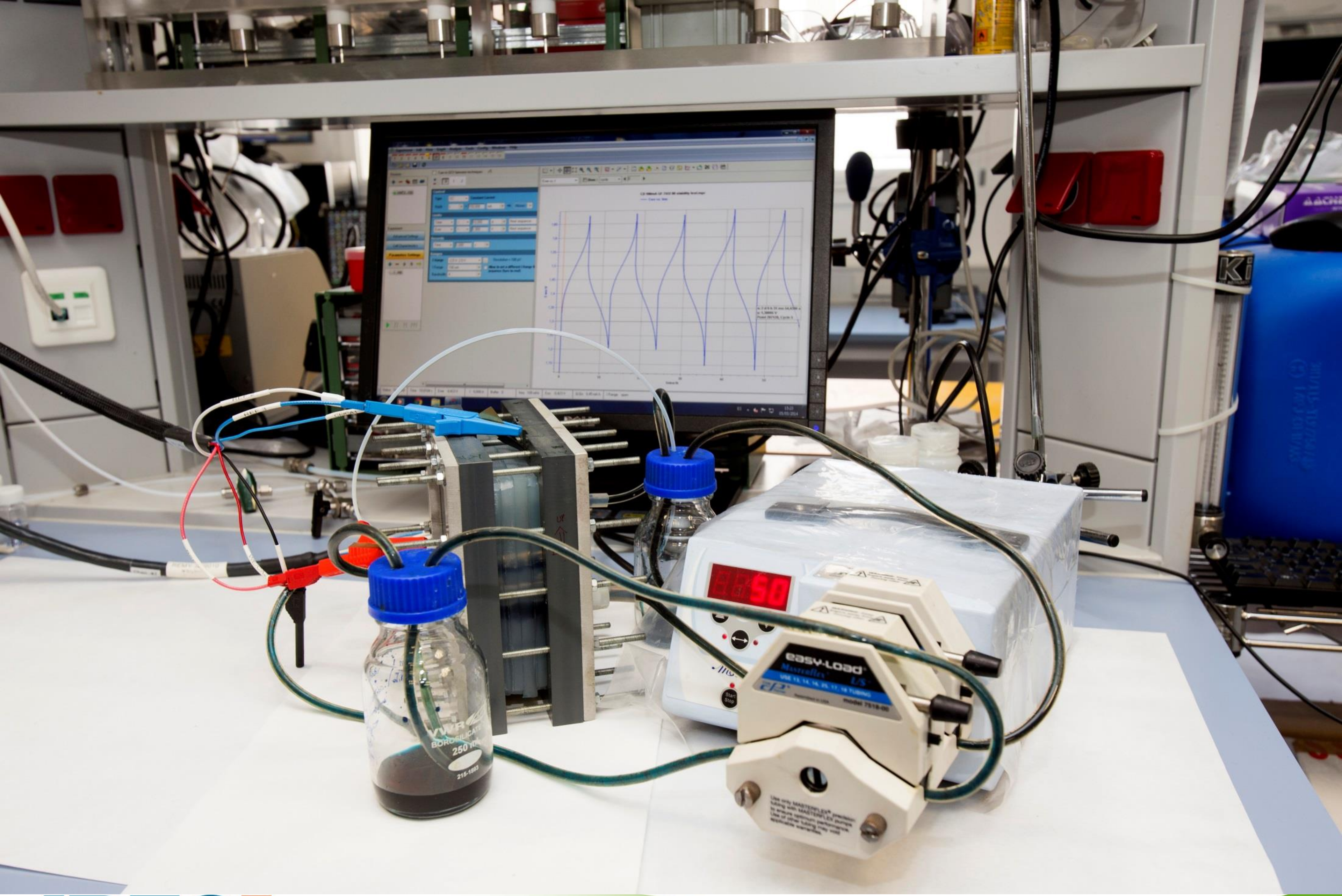

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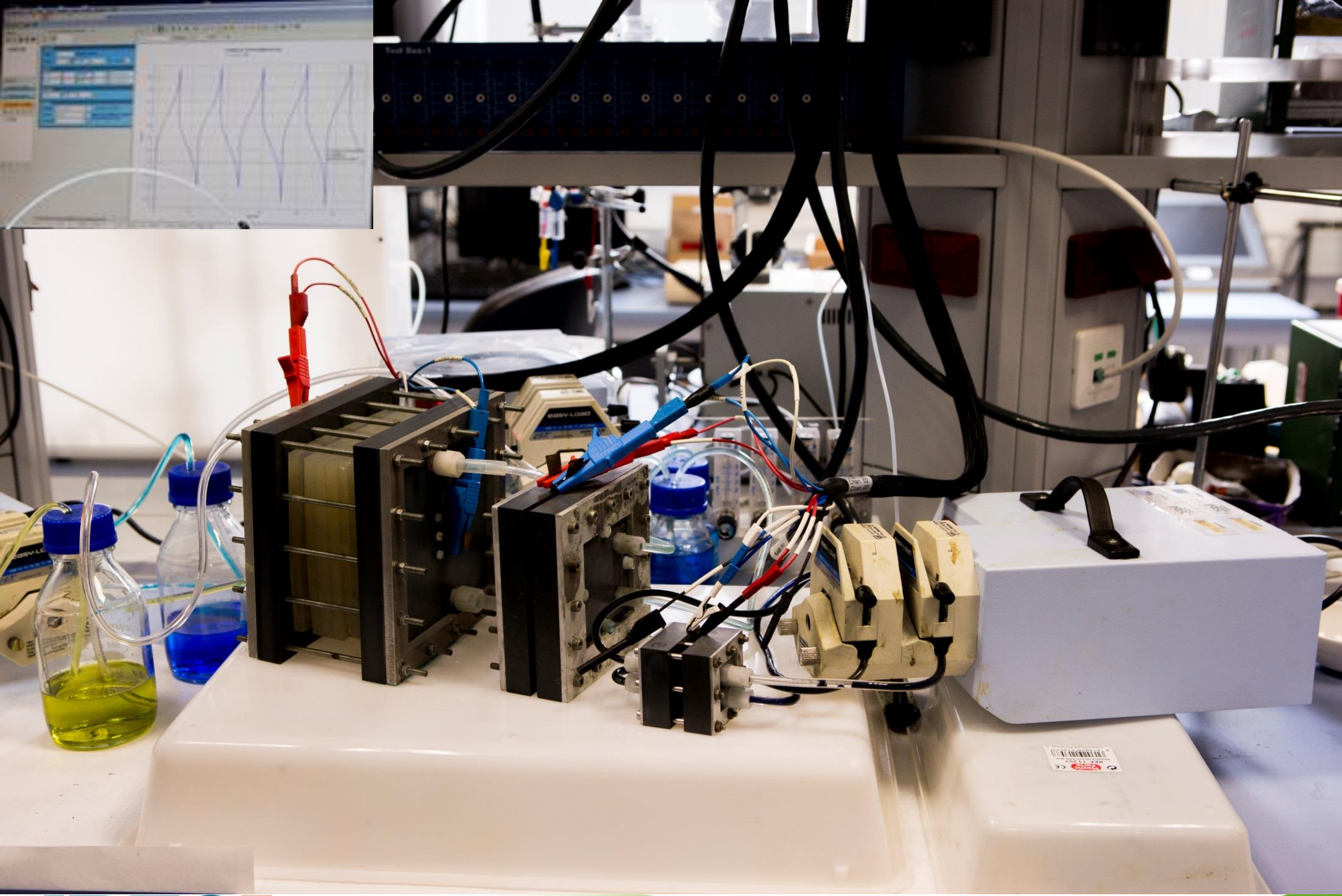

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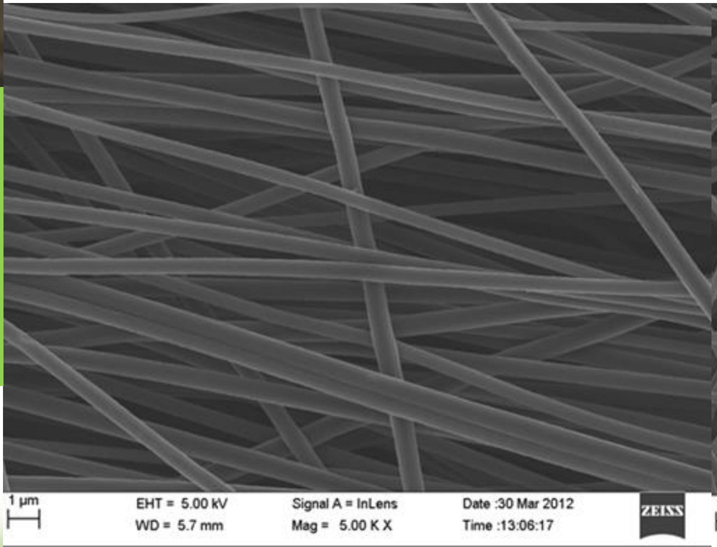
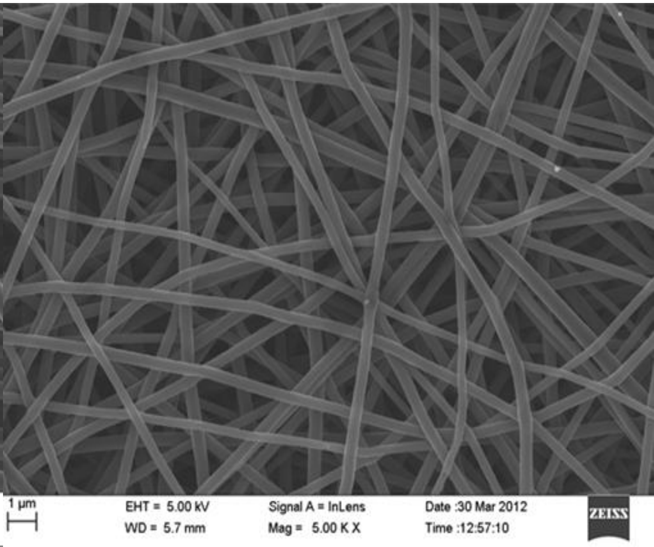
Example of one of the used electrode materials





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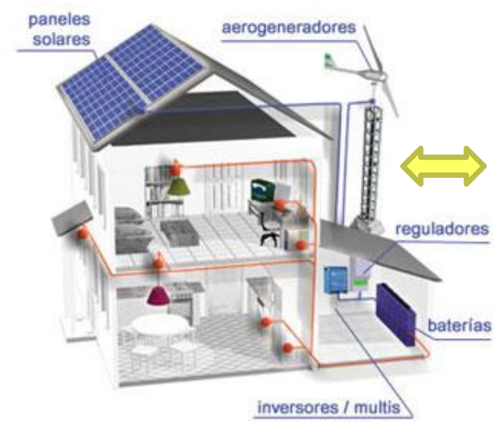
CONCEPT: **Energy Storage Smart System for End Users**

BAPV + BIPV
+ Other renewals sources



Smart Power Electronic Conditioner

Grid

Smart Metering

E Storage

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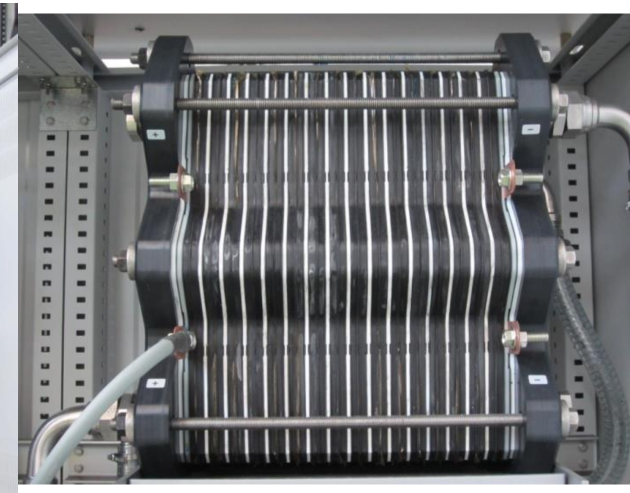
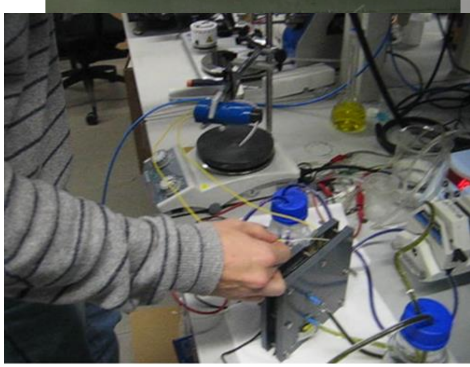
Prototype





Número de celdas: 20
Voltaje: 30V
Corriente: 50 A
Potencia: 1.5 kW

KIC EES PROJECT

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ZIGOR

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STORING ELECTRICITY IN LIQIDS!

VOLTERION REDOX-FLOW-BATTERIES

- High efficieny
- Long Lifetime
  > 10.000 cycles
- Not flammable, non explosive
- Independent scaling o
  power and capacity
- Recycable electrolyte

REDOX-FLOW-MODULES

http://www.volterion.com/eng-1/

Module for 2 kW Power
Automatic optimization of self consumption
complete process integration
compact size
Tanks/ housing / electrolyte custom designed

http://www.imergy.com/products

Output Power:
5 kW

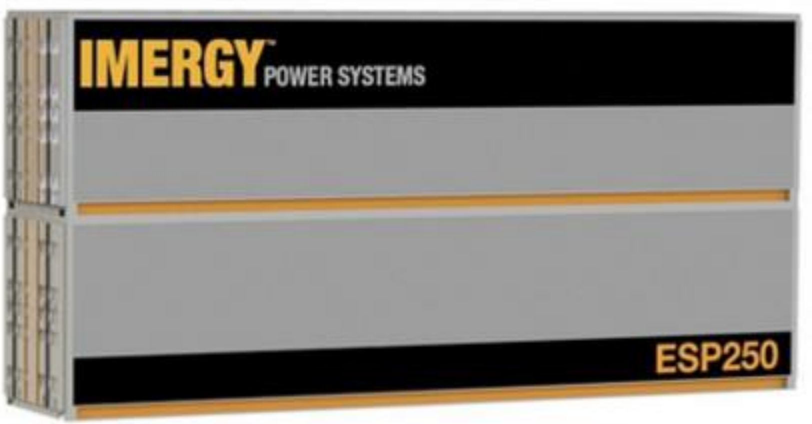
Capacity Range:
15-30 kWh at 100% depth of discharge

Dimensions:
7.1 x 4.4 x 6.8 ft

Output Power:
15 – 45 kW

Capacity Range:
120 - 200 kWh at 100% depth of discharge

Dimensions:
20 x 8 x 8.5 ft (20 foot shipping container)



Output Power:
250 kW

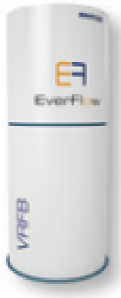
Capacity Range:
1 MWh at 100% depth of discharge

Your Energy. Our Solution.

The SCHMID EverFlow® Product Family

EverFlow® Compact Storage

The solution for applications with an output of 2 and 5kW and with an energy content of 12 to 50kWh: Compact design for easy building installation in single- and multi-family houses, for commercial purposes or telecommunication.

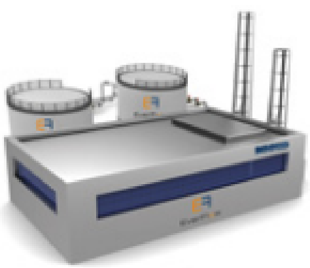


EverFlow® Container Storage

The container storage in the range of 10 to 45kW and up to 150kWh for fast installation and safe operation. An optional air conditioning ensures stable operating conditions. A building integration is possible.

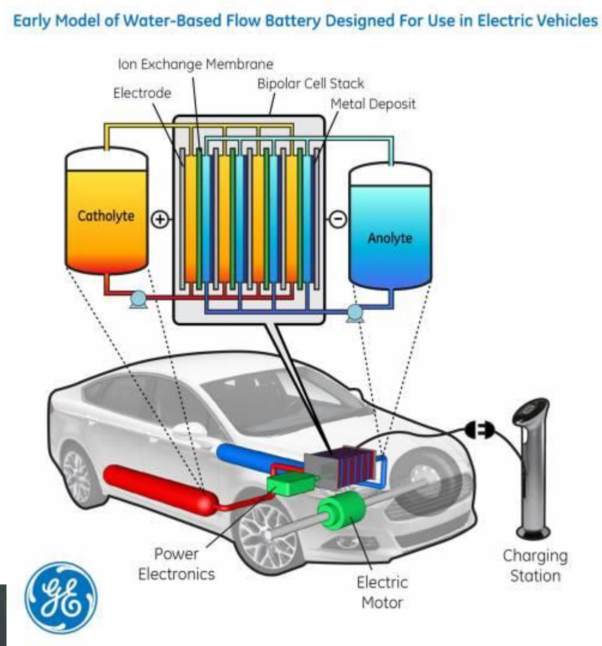
EverFlow® Large Scale Storage

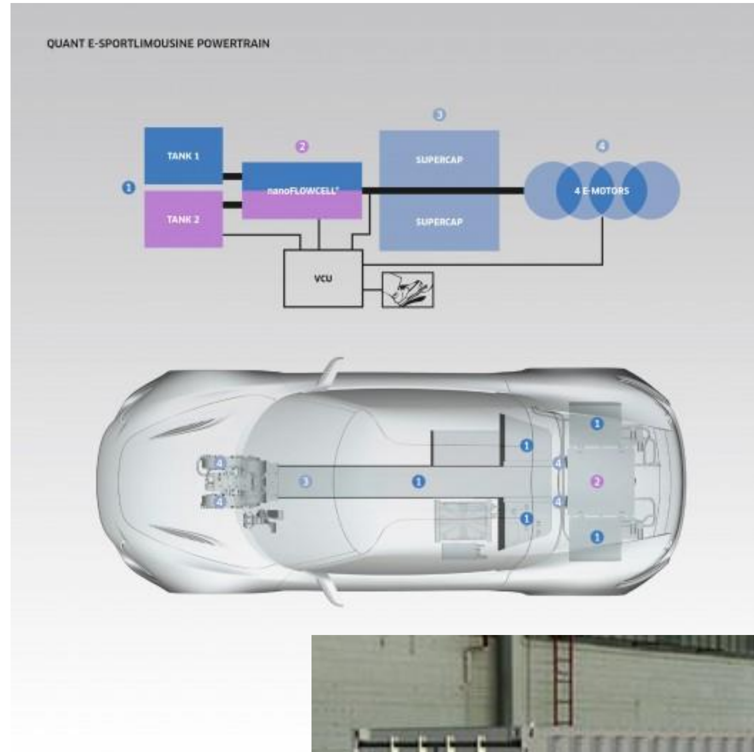
The storage solution for large industrial plants and residential areas with an output of at least 200kW.



http://www.schmid-energy-systems.com/files/portfolio_everflow.pdf

Prototipos comerciales para almacenamiento estacionario y movilidad





VRFB 5kW Stack – Building block

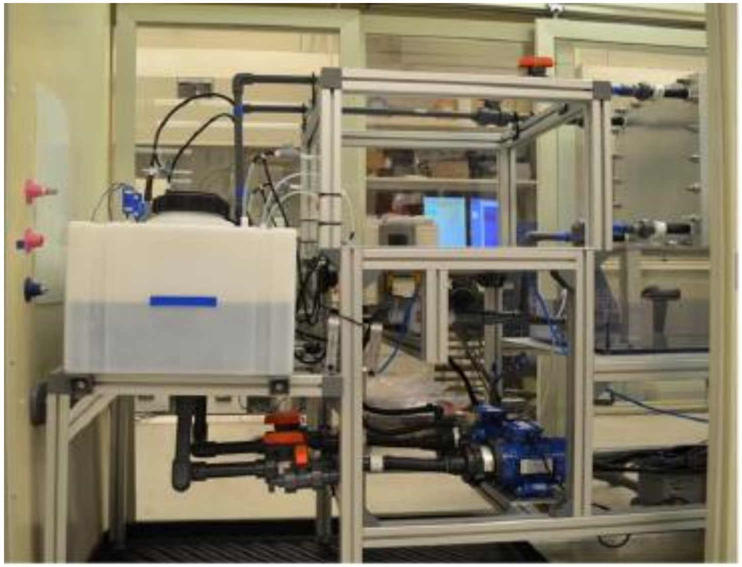
All polymer materials, high integrity sealed system

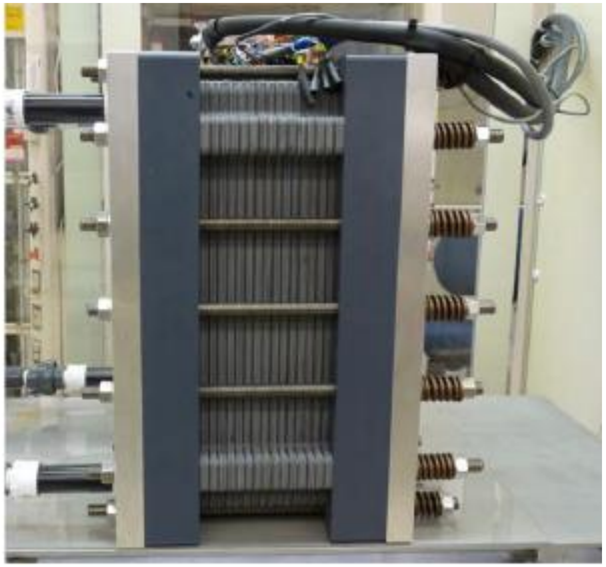
Low impedance membrane electrode structure

Charge/discharge ratio 1:1

5kWe nominal,
8.5kWe peak (15 mins)

Future target of 15kW





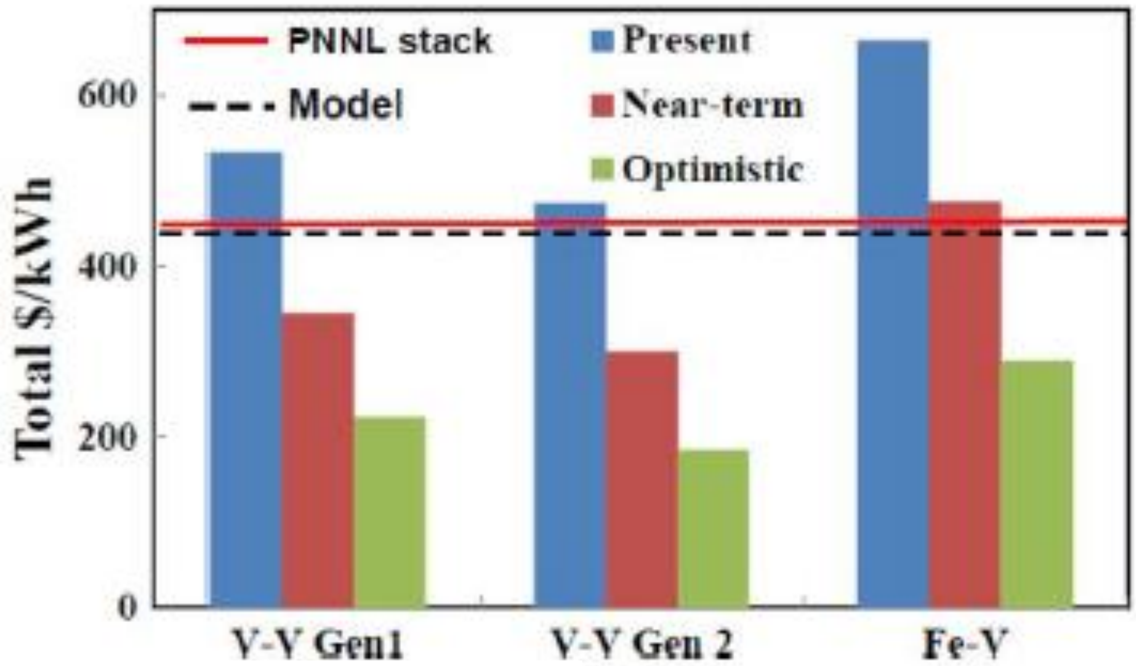
	Columbic Efficiency (%)	Voltage Efficiency (%)	Energy Efficiency (%)
80 mA/cm²			
Nafion® 115	95.2	86.9	82.7
Nafion® 212	95.6	89.9	86.0
160 mA/cm²			
Nafion® 115	95.8	77.6	74.4
Nafion® 212	96.5	82.2	79.4
240 mA/cm²			
Nafion® 115	-	-	-
Nafion® 212	96.6	76.1	73.5

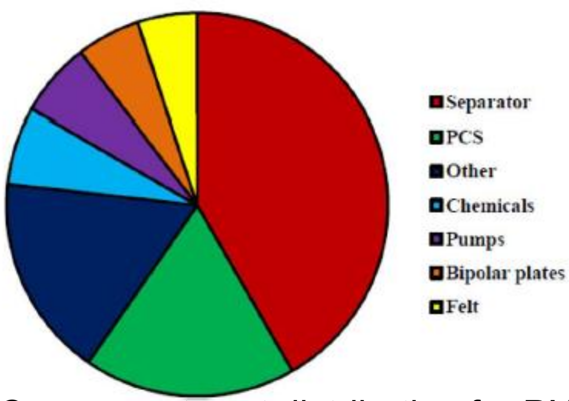
PNNL 1.2-kW/1-kWh all-vanadium redox flow battery.

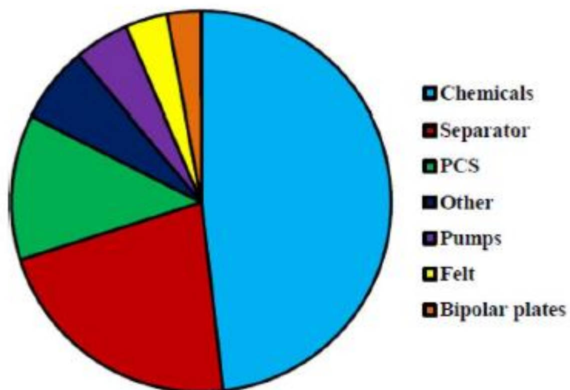
(a) Stack with balance of plant.

(b) Stack

Total capital cost for 1-MW RFB systems for three different electrolyte chemistries for the 4-MWh system







Component cost distribution for PNNL's all-vanadium Gen-2 chemistry. Chemical costs dominate for the 1-MW/4-MWh system at 48%, while separator material costs are 22%. As expected, for the 1-MW/0.25-MWh system, stack costs dominate, led by membrane costs at 42%.

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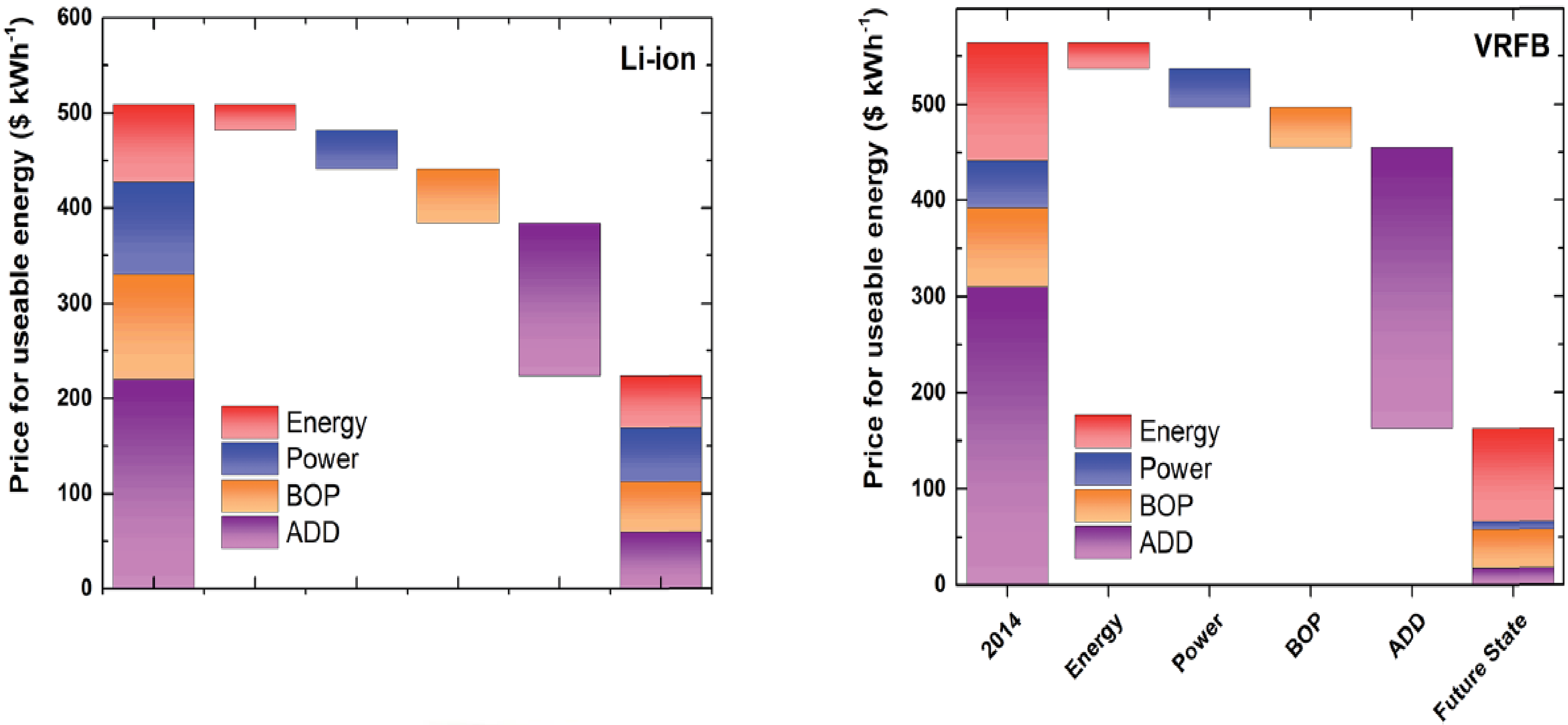

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Original 30kWh VRFB pilot system

- Community owned Wind
- Population ~150
- Tourism, Farming, Brewing
- Renewables potential
- Sub-sea cable
- One of the longest 11 kV feeders to mainland
- Remote and wild

The Isle of Gigha and the Application

The Isle of Gigha and the Application

REDT

Current position:

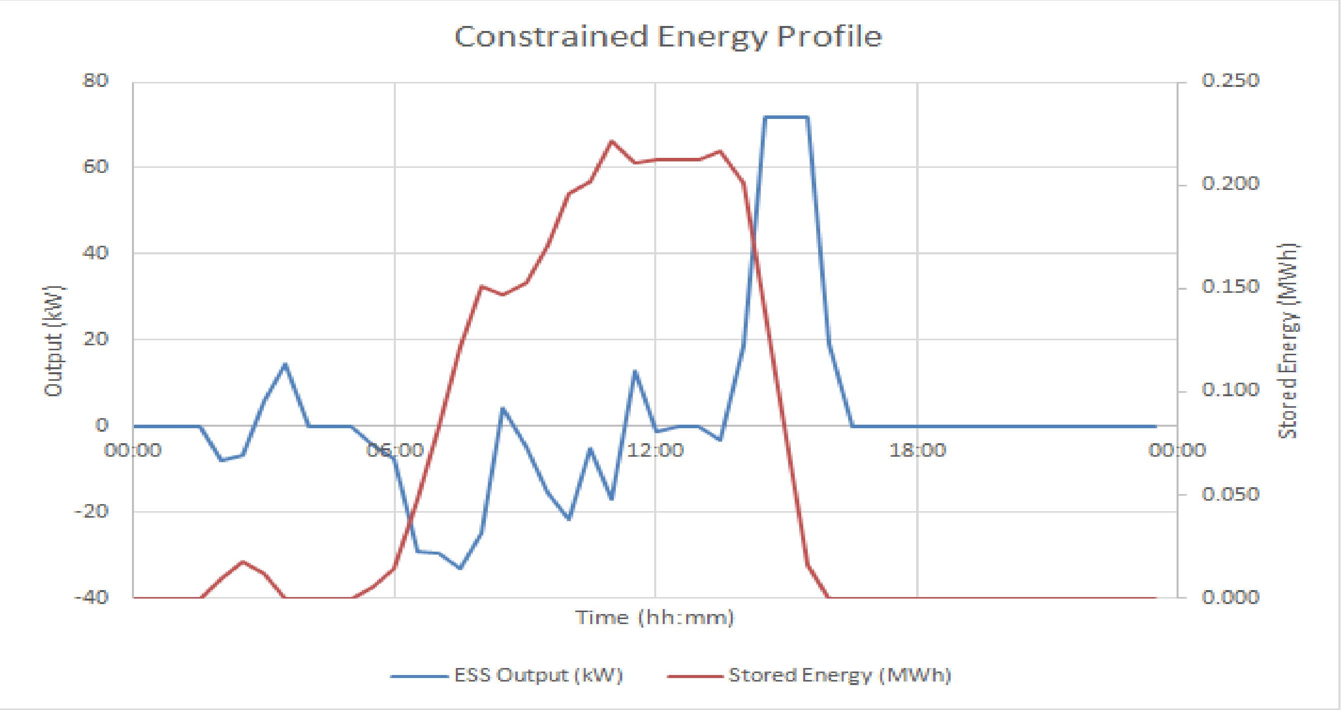
- New (4th) wind turbine installed - exceeds T&D limits
- 330 kW constrained to 225 kW at 0.85 p.f.
- Line capacity upgrades not yet available
- Lose 3 GWh over asset life

Primary objective:

- Constrained energy recovery with on- peak dispatch
- Enhanced FIT benefit
- Opportunity to increase RE generation by 30%

Constrained Energy Profile – Typical day
Gigha system 105kW x 1.26MWh

Blue = ESS kW, Charging when negative   Red = Stored energy MWh
start/finish @ zero SOC



Wind	330 kW	Data from Assessent Tool v1_7
Solar	105 kW	Markers in orange in Data worksheet
ESS Rating	105 kW	

Process for determining the profile
Find a 'typical' day of constrained operation for the ESS, by simulation of the ESS operation in a Wind + PV constrained Gigha application.
Typical day has been chosen as a day for which the constrained energy output was the 50th percentile = 15/02/2012
Choose 48 half-hours residing mainly in the 15/02/12 day, for which the ESS could start and end at the same SOC (zero in the below).

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System Services Summary

Frequency Control

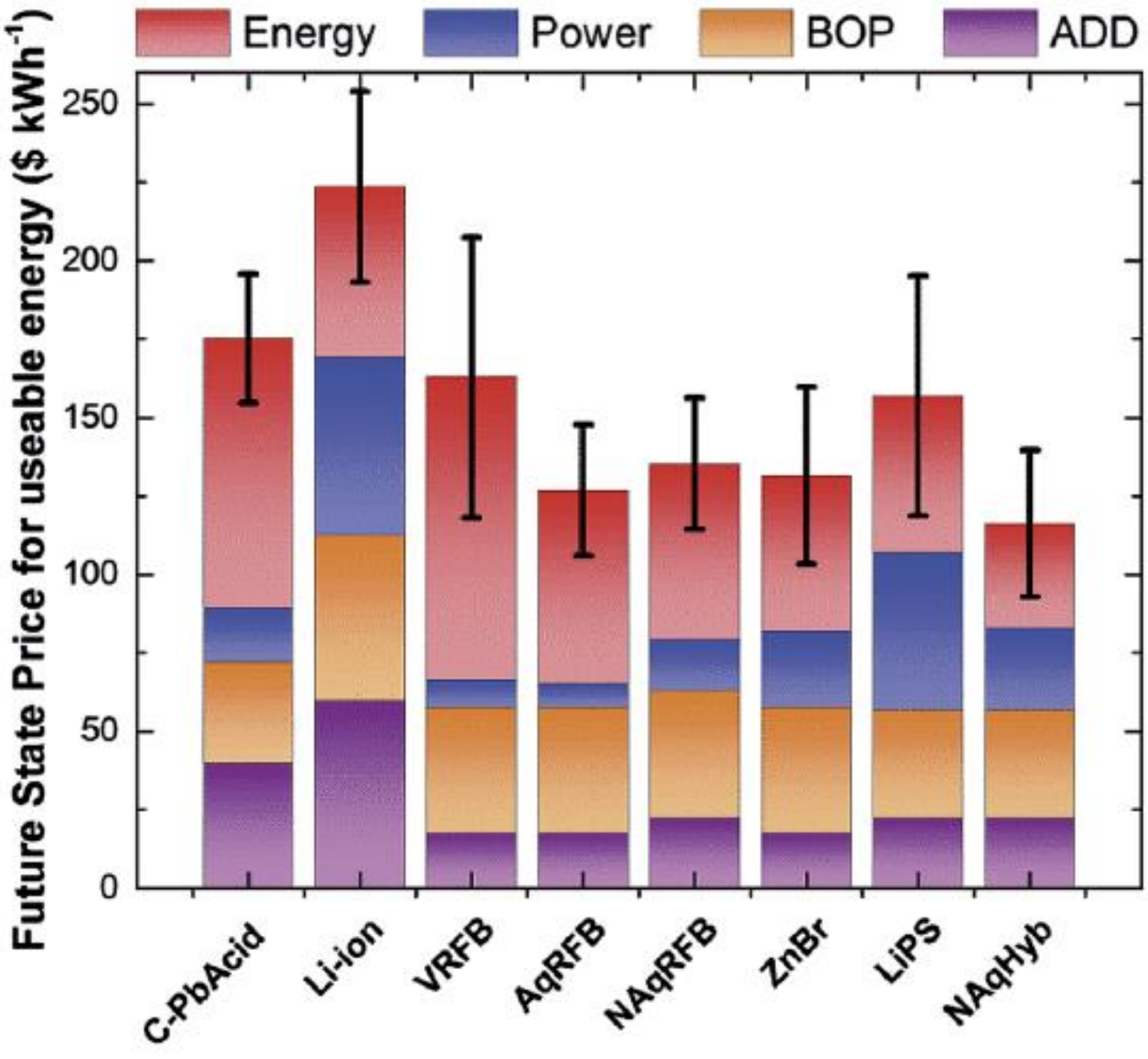
Voltage Control

Regulation of Curtailment

Arbitrage

Improvement of output prediction

Post demonstration stage the technology will be rolled out to other islands



R. Darling et al. EES (2014)

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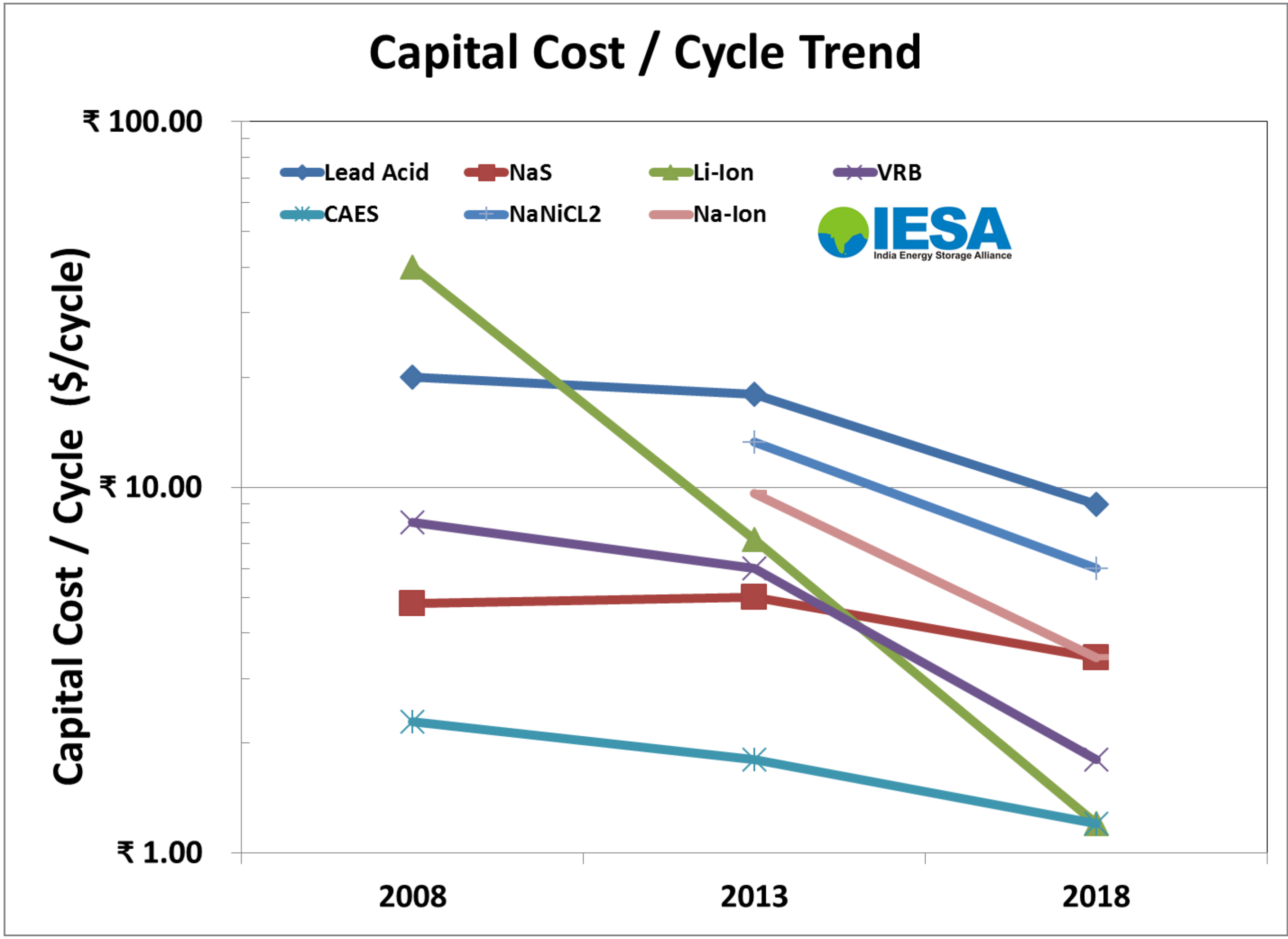
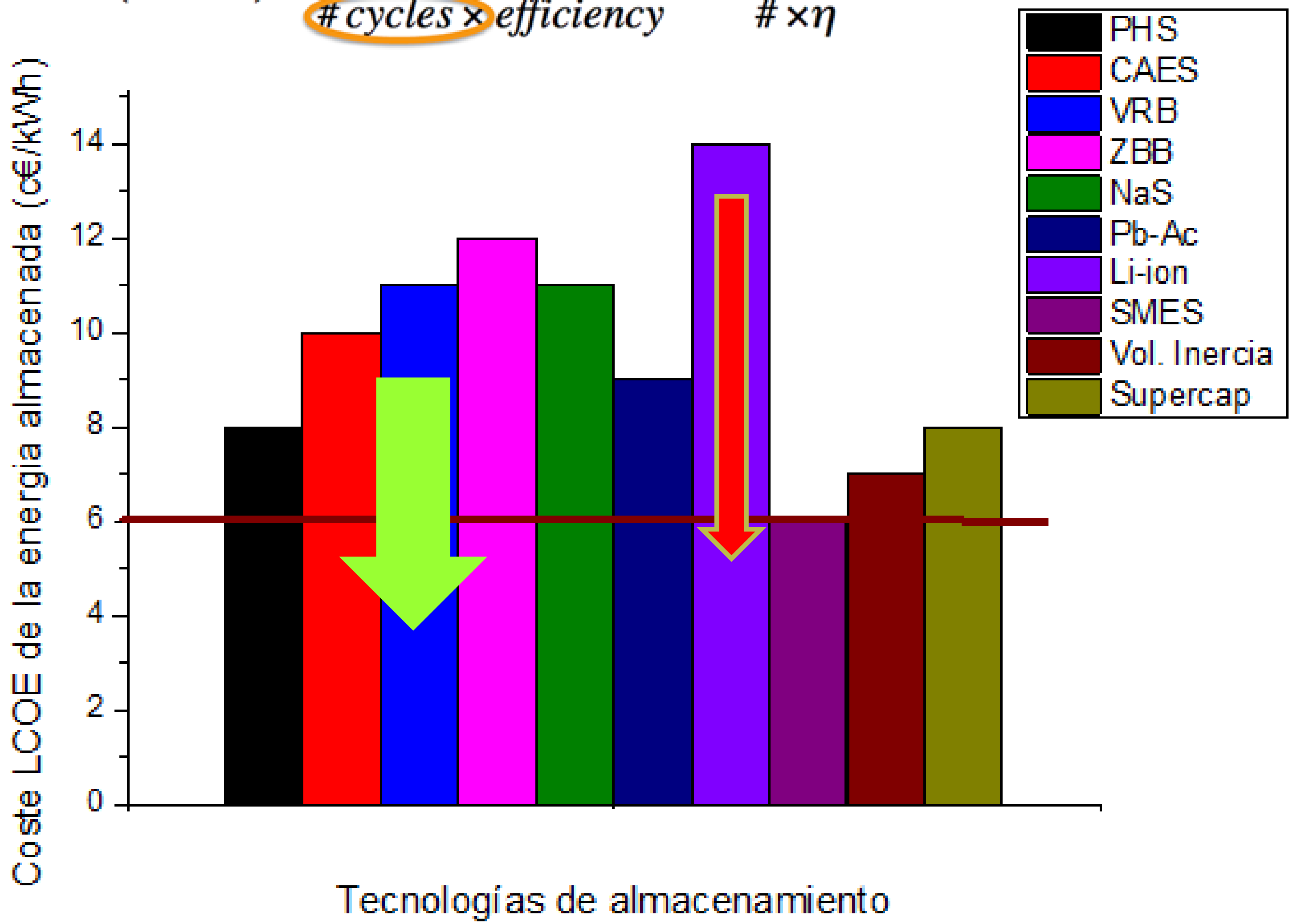
Cost reduction in per Cycle Capital Costs



$$LCOSE(\$/kWh) = \frac{Cost}{\# cycles \times efficiency} = \frac{(\$/kWh)}{\# \times \eta}$$



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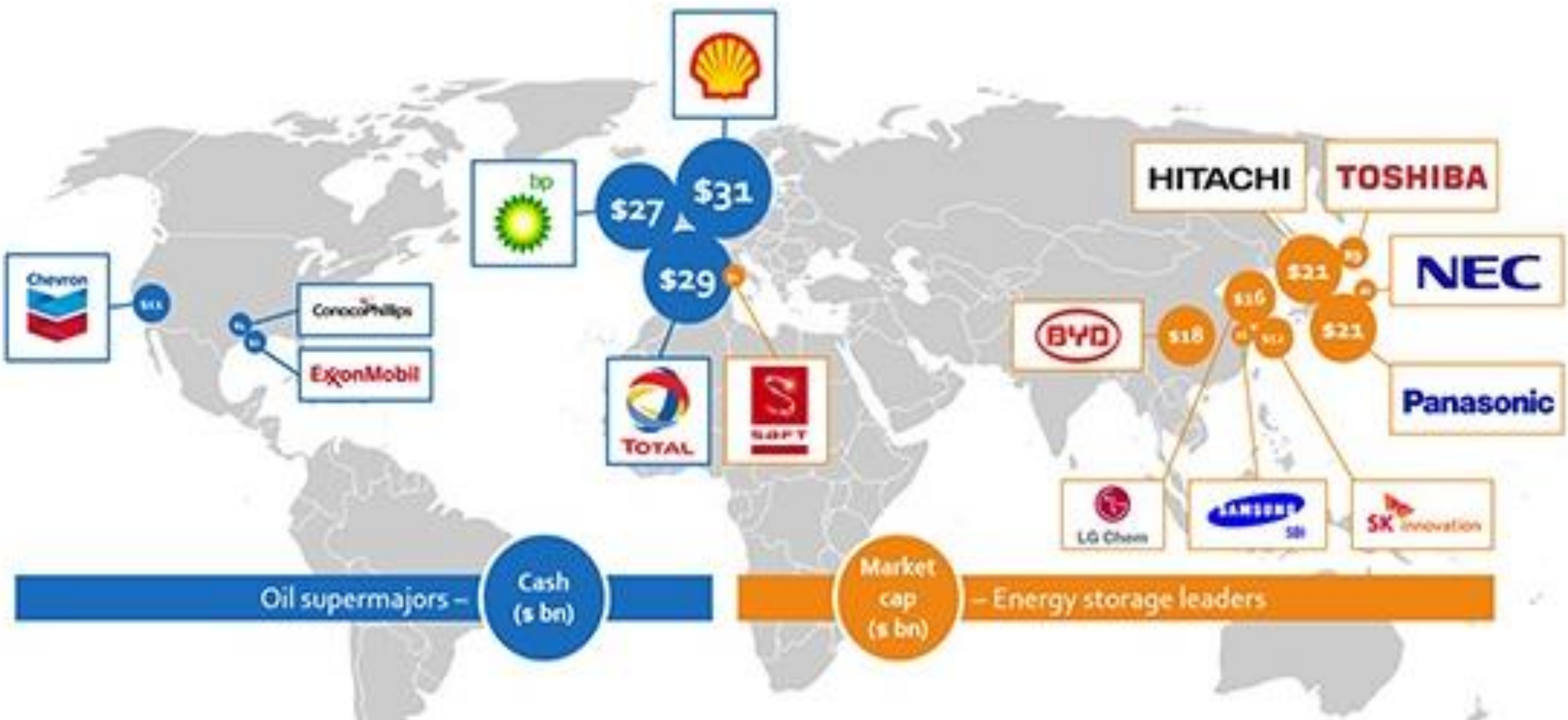
Integration of 1 MW/5 MWh of flow battery system for load leveling and peak shaving at Sumitomo Yokohama Works. (Photo Sumitomo Electric Company.

Big Oil Meets Energy Storage

There Is a Geographical Separation between Oil Supermajors and Most Battery Players



Notes: Cash includes short-term investments. Market capitalization indicator is based on Q2 2016 data from following stocks: LG Chem's KRX:051910, Samsung SDI's KRX:006400, Panasonic's TYO:6752, Saft's EPA:SAFT, BYD's SHE:002594, NEC's TYO:6701, Hitachi's TYO:6501, Toshiba's TYO:6502, and SK Innovation's KRX:096770

5 FUTURO DE LAS BATERIAS DE FLUJO

ALGUNOS DATOS PARA UNA CASA RESIDENCIAL

Antes de impuestos

Consumo eléctrico anual: **4000 kWh/a (<12kWh/dia)**

Capacidad de generación de electricidad PV: **1600kWh/kWp (Sur España)**

Precio Pagado de la electricidad de la red incluyendo tasas, impuestos, tramos fjjos: > **25 cts/kWh**

Precio del sistema PV instalado: **1000-1500 €/kWp**

Datos instalación: Sistema **3kWp** PV y una batería de **15 kWh**
Cobertura solar > 95%

Fuente. IREC

Costes básicos generación solar **<6 c€/kWh**
Costes básicos almacenamiento **3-6 c€/kWh**

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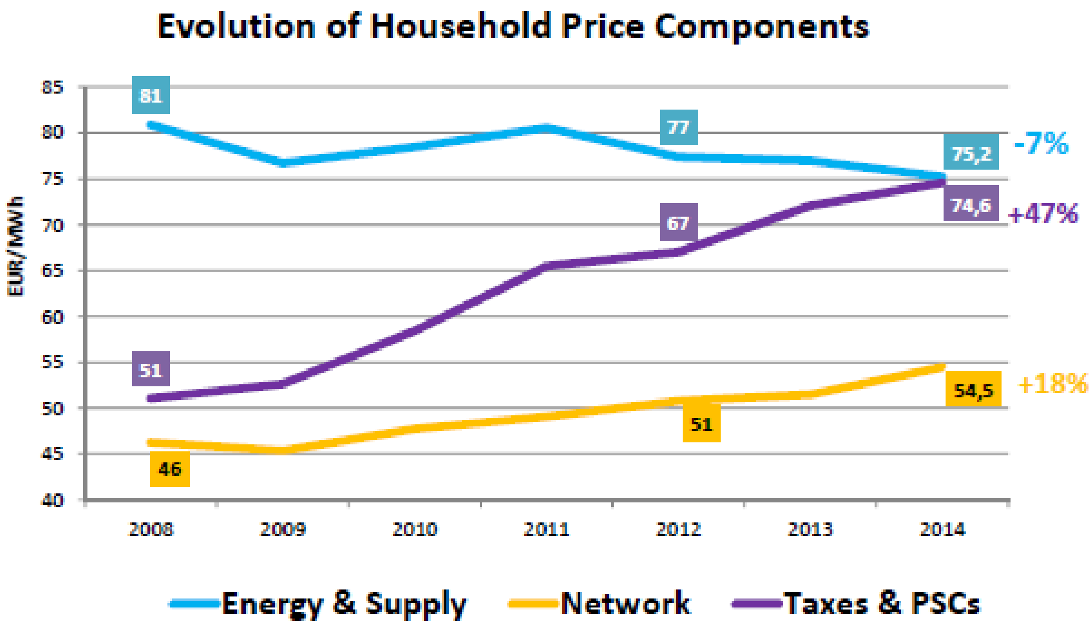
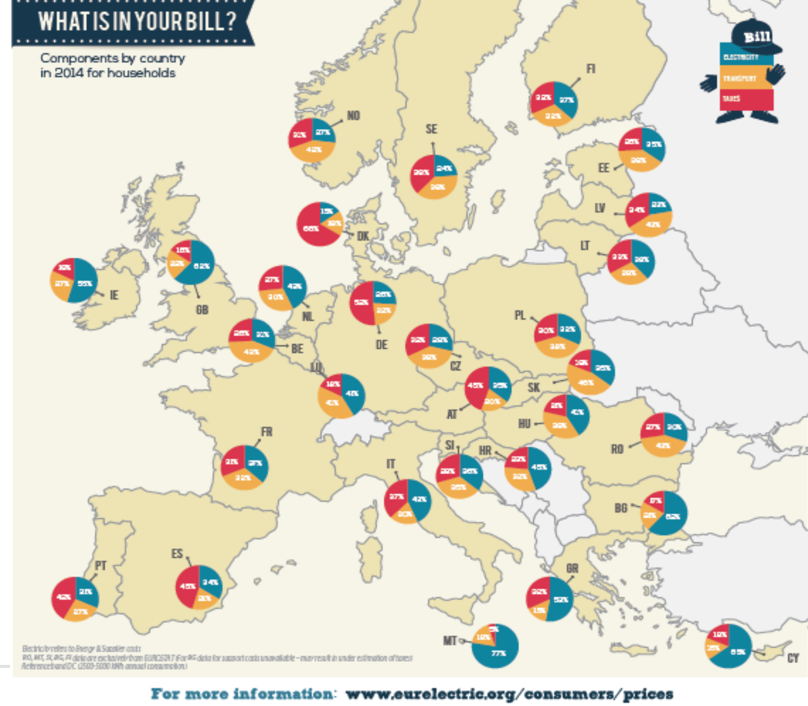
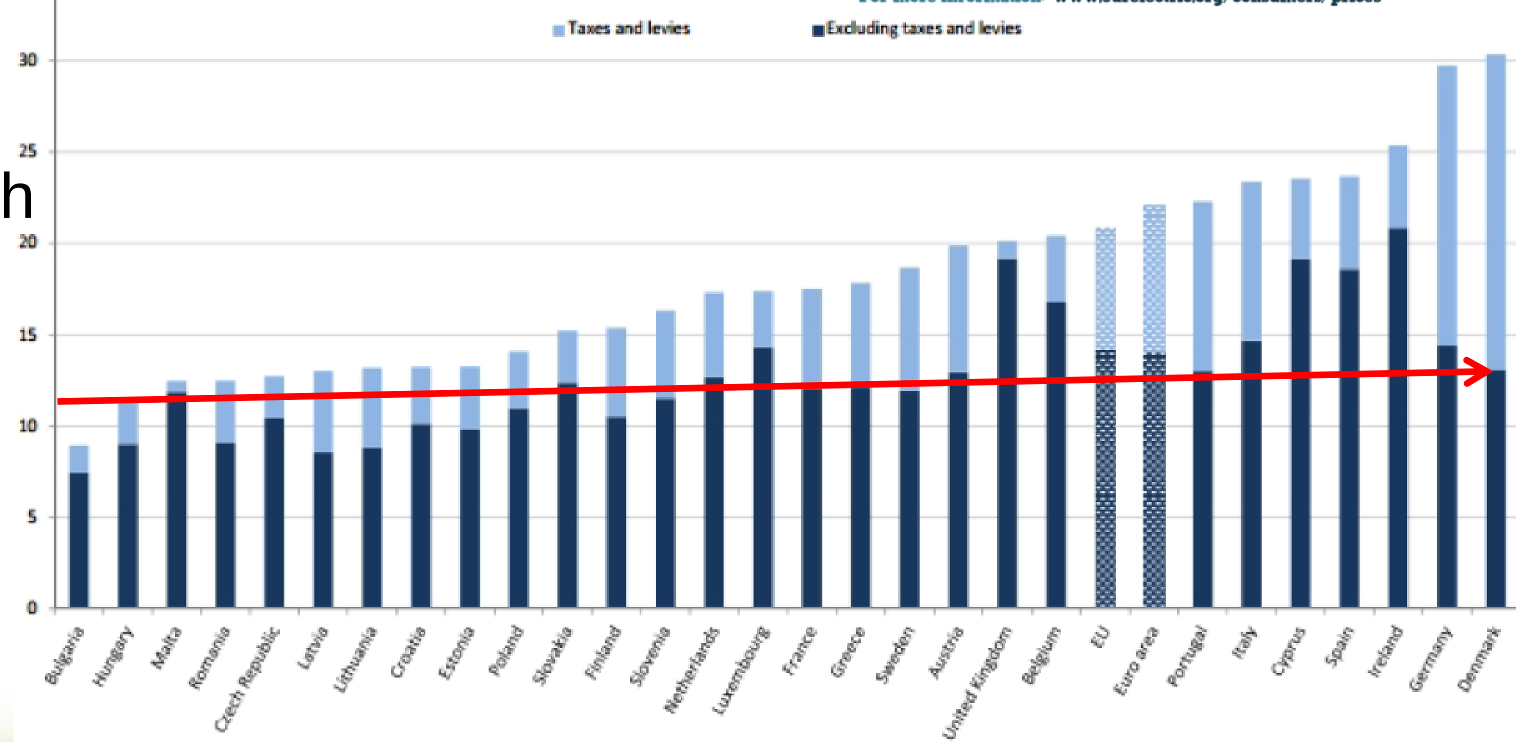




c€/KWh



Versus
60€+60€/MWh

Source: Eulectric

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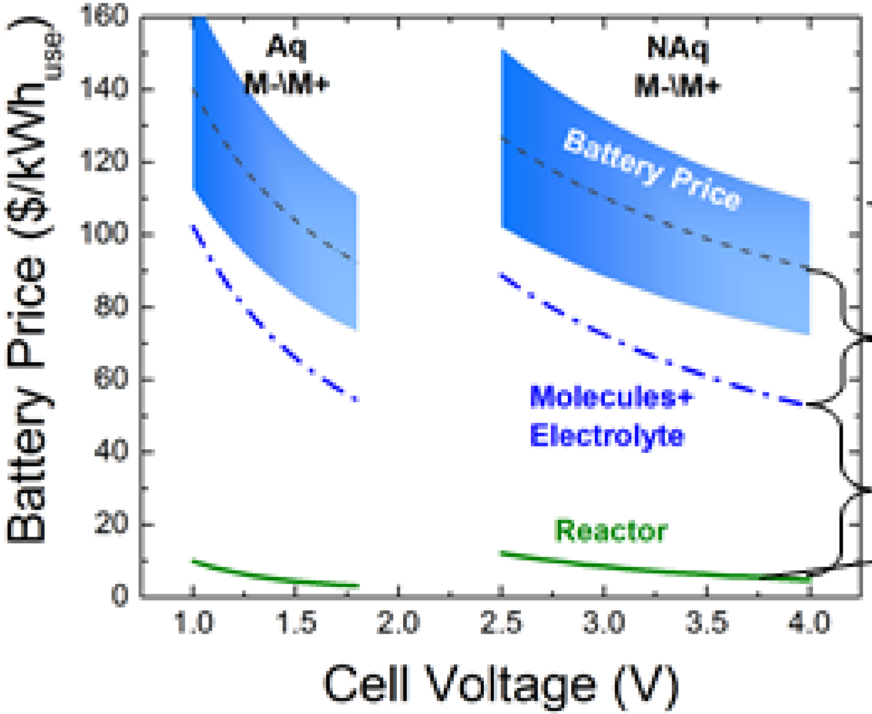
Ejemplo:

INSTALACIÓN FOTOVOLTAICA DE 17,25 KWp

Objectivo: Autoconsumo

- Campo Fotovoltaico: 69 Panales de 250 Wp
- Ondulador: Trifasico15 KW
- Gestor sistema: 3 VictronMultiplus48/5000/70
- Almacenamiento: 24Baterías 2V OPZs800 Ah C10
- Autonomía: 3 h.
- Ahorro aproximado >25.000 KWh/año



Battery price + uncertainty

System + Additional contributions to price

Energy = molecules + electrolyte

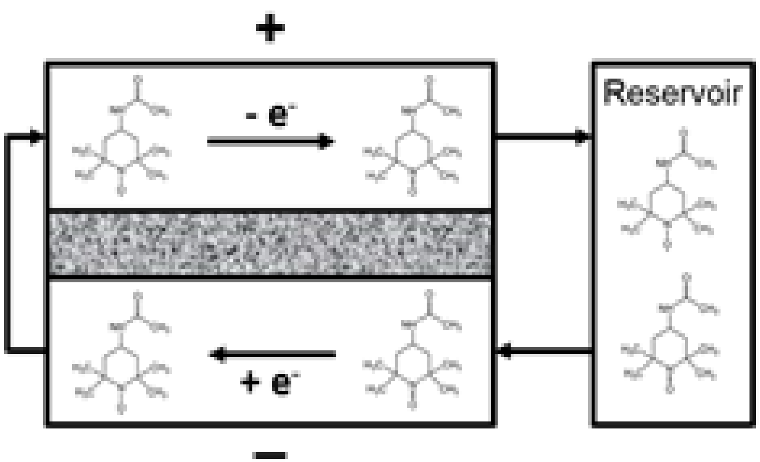
Power = reactor

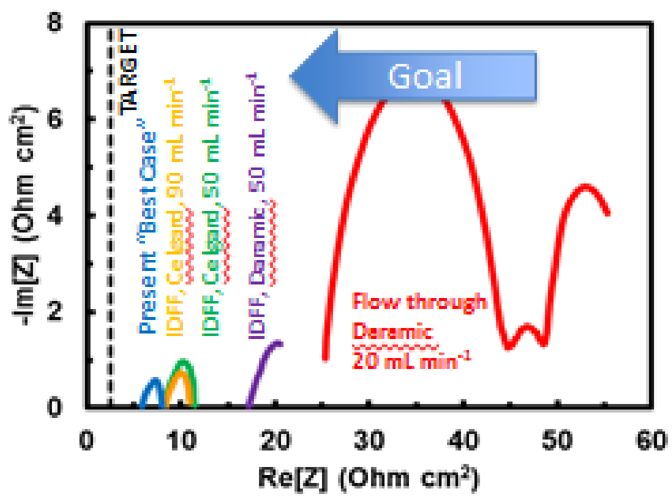
Properties	NAq	Aq
$U_{avg.}$ (V)	3	1.5
ASR (Ω-cm²)	5	0.5
Capacity (g/mol e-)	150	150
Solubility (kg/kg)	0.8	0.05
Concentration (mol/L)*	~4-5	~1-2
Material Cost ($/kg)	5	5
Electrolyte Cost ($/kg)	5	0.1

**Assuming 1 g/mL electrolyte density*

__high power__ systems

Current Density:	80-130 mA cm^{-2}
Area Specific Resistance:	2.5 – 4.0 Ω cm^2
Voltage Efficiency:	91 - 93%
Cell Potential:	3.5 V
Overpotential Losses:	320 – 325 mV





Darling, Gallagher, Xie, Su, Brushett, "Transport Property Requirements for Flow Battery Separators," J. Electrochem. Soc., 2016,
DOI: 10.1149/2.0051601jes

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CONCLUSION: CIENCIA Y TECNOLOGIA ESTAN CONTRIBUYENDO A INTRODUCIR MEJORAS PERO HAY QUE INSISTIR EN:

1.-REGULACION
2.-LEGISLACION
3.-EFICIENCIA ECONOMICA
4.-SOLIDARIDAD SOCIAL
5.-ESTRATEGIA POLITICA

DEBEB ACOMPAÑAR A LAS ACCIONES PARA

- **ASEGURAR ACCESO A LA ENERGIA ABUNDANTE Y BARATA**
- **FACILITAR Y FAVORECER EL USO DE ENERGIAS RENOVABLES RESPECTABLES CON EL MEDIO AMBIENTE**
- **CONSTRUIR UN FUTURO ENERGETICO EN BASE A LA EFICIENCIA.**

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jrmorante@irec.cat
New call for PhD EU program
Marie Curie
https://projects.icmab.es/docfam/

Thank you.

$CO + H_2$

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Ciemat

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Universitat de Barcelona

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enagas

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