GES

July 28th, 2023
Summer School on Energy Storage

GES TECHNOLOGY FOR LONG DURATION ENERGY STORAGE

Hybrid Redox Flow Battery

TABLE OF CONTENTS

ABOUT GES

GREEN ENERGY STORAGE

Who we are?

Innovative Italian SME founded in **2015**

R&D of Redox flow battery technologies:

- Alternative to Li-ion for stationary application (especially for long discharge time >4h)
- Cost effective (€/kWh/cycle)
- Based on abundant redox species (non-critical materials in EU)
- Environmentally friendly and safe

Recognized as **leading actor** in **Important Project of Common European Interest** (IPCEI): recently was granted with a **62 M€ budget** project to develop a new RFB battery technology.

Where are we based?

We are based in

- **Trento**: Via alla Cascata 56/C 38123 Povo (TN)
- **Rovereto**: Piazza della Manifattura, 1, 38068 Rovereto (TN)

GREEN ENERGY STORAGE

R&D Collaborations

- **University of Pisa**:
  - **Industrial PhD** on the *synthesis of membranes for RFBs 2021-2024*
- **University of Trento**:
  - **Internship** on *Membranes and electrode assembly (MEA) preparation and testing - 2021*
  - **Internship** on *Commercial electrodes benchmarking (Cathodes) – 2022*
  - **Master thesis** on the development of carbon nitride-based catalyst for RFBs - 2023
  - ***Internship*** *on Analytical Study of Channel Geometry in the Bipolar Plate of a Redox Flow Battery through Python simulations – 2023*
- **University of Padua**:
  - **PhD on cell design** *2023-2026*
- **Fondazione Bruno Kessler (FBK)**

Patents

- 1 in draft
- 2 on Catholyte chemistry and composition - 2022
- Aqueous anolyte composition for flow battery system - 2021
- Catholyte chemistry for Hydrogen flow battery, hybrid system gas + liquid - 2021
- Harvard AQDS TECHNOLOGY PATENT License Agreement - 2015

IPCEI FOR THE EUROPEAN BATTERY INNOVATION PROGRAM

IPCEI (Important Projects of Common European Interest)*
GES was granted with a 62 M€ budget project to develop a new RFB battery technology.
The funding covers the activities of a 4-year R&D and a 2-year first industrial deployment (FID)

BUDGET: 62 M€ (GES)

DURATION: 6 YEARS
(4 YS R&D + 2 YS FID)

PROJECT: NEW RFB TECHNOLOGY FROM R&D TO FIRST INDUSTRIAL DEPLOYMENT (FID)

*IPCEI is a category of projects that the European Commission has identified as a **key priority to interconnect the energy infrastructure in the European Union**

GES HYBRID RFB

- RFB general properties
- RFBs performance metrics
- GES hybrid RFB properties

GES HYDROGEN FLOW BATTERY

Flow battery with a **unique electrolyte** that **produces the hydrogen** necessary for charge and discharge cycles.
Energy and power decoupling enables to tailor-made the product to meet all the requirements, from residential to utility scale.

ELECTROLYTE

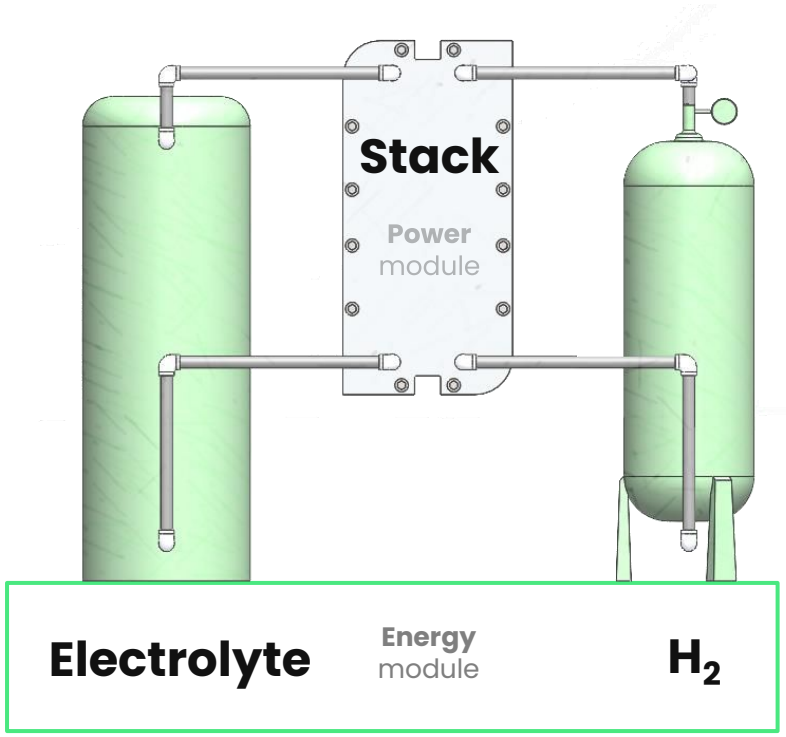
LIQUID
Electrolyte covered by GES patent protection

SINGLE
Compared to traditional flow batteries, having a single electrolyte represents an advantage in terms of production cost (halved quantity of raw material) and eases the supply chain

NON-CORROSIVE CHEMISTRY
In addition to the direct benefit in terms of safety, anti-corrosion materials are not required

SIMPLE MAINTENANCE
Easier and cheaper maintenance compared to alternative technologies

EASY CHEMICAL HANDLING
The chemistry will be produced by an external supplier and the electrolytes introduced into the final product downstream of the production process or directly at the customer's site



H_2

SELF HYDROGEN PRODUCTION
During the charging phase, the battery produces the hydrogen necessary for storage which will be self-consumed in the discharge phase

ESTABLISHED TECHNOLOGY
Hydrogen management technology is already well established, known and increasingly cheap

NO H_2 LOGISTICS
Unlike fuel cells, a separate external hydrogen supply system is not required

REDUCTION OF PRODUCTION COSTS

1. GES, together with its partner Manica, has **already experienced and developed an effective methods** for reducing chemistry costs
2. The stack production cost has already decreased in the last few years. In addition to this, GES has the relevant know-how on membranes and electrodes
3. GES will benefit from the significant cost reduction expected on hydrogen technology given by the **growing worldwide investments**

HOW DO RFBS WORK?

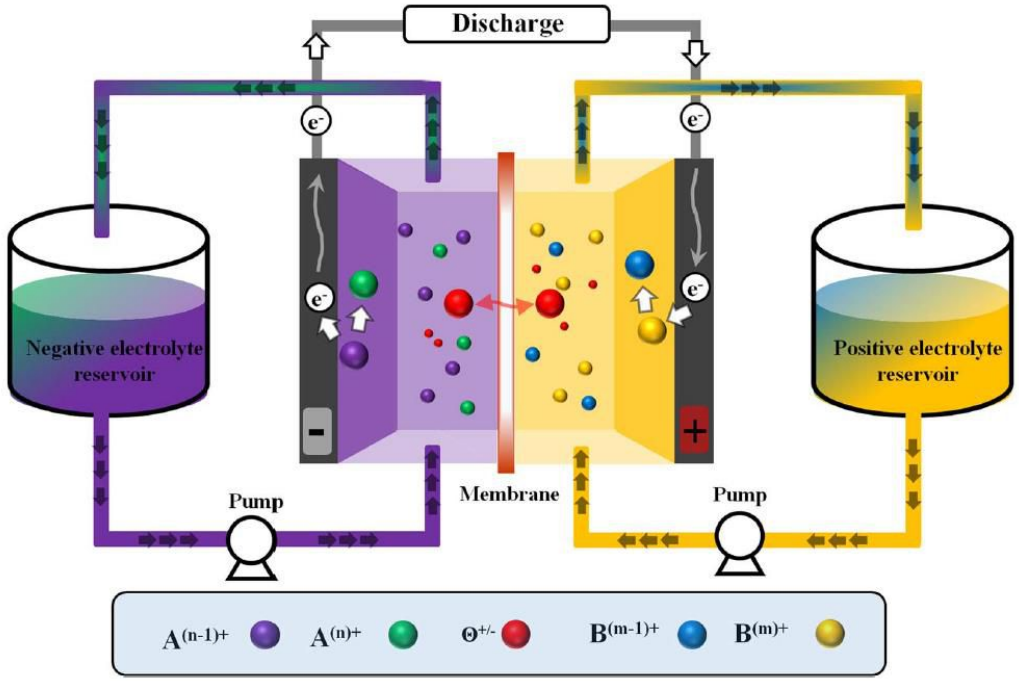
Oxidation

$$AH \longrightarrow A + H^+ + e^-$$

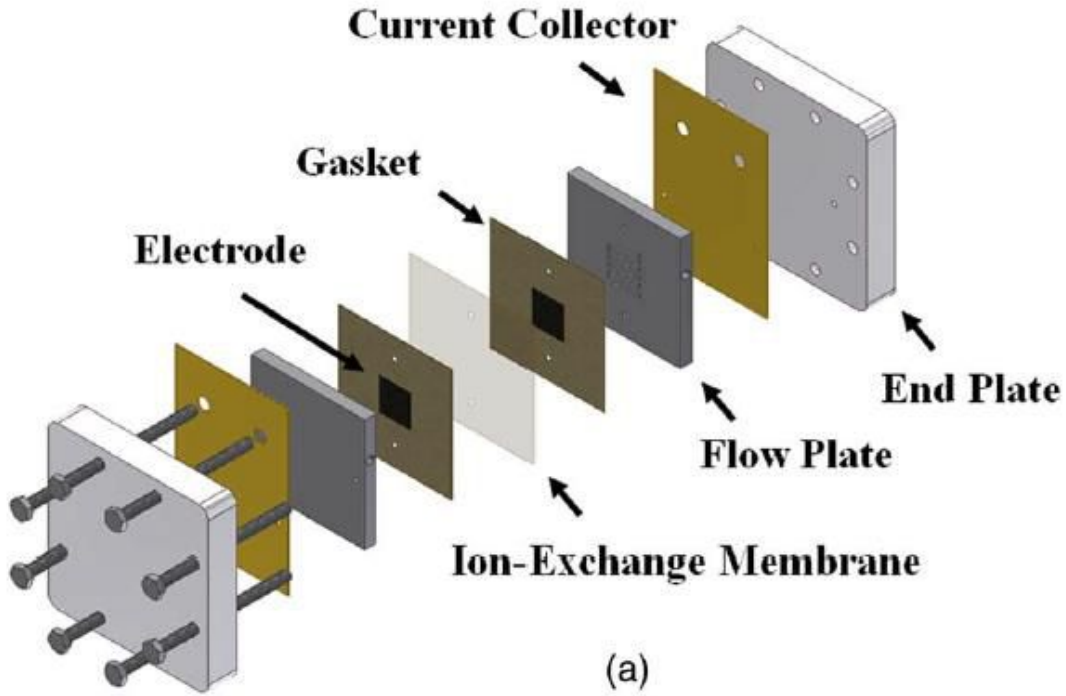
Reduction

$$B + H^+ + e^- \longrightarrow BH$$

During charge redox reactions are reversed.

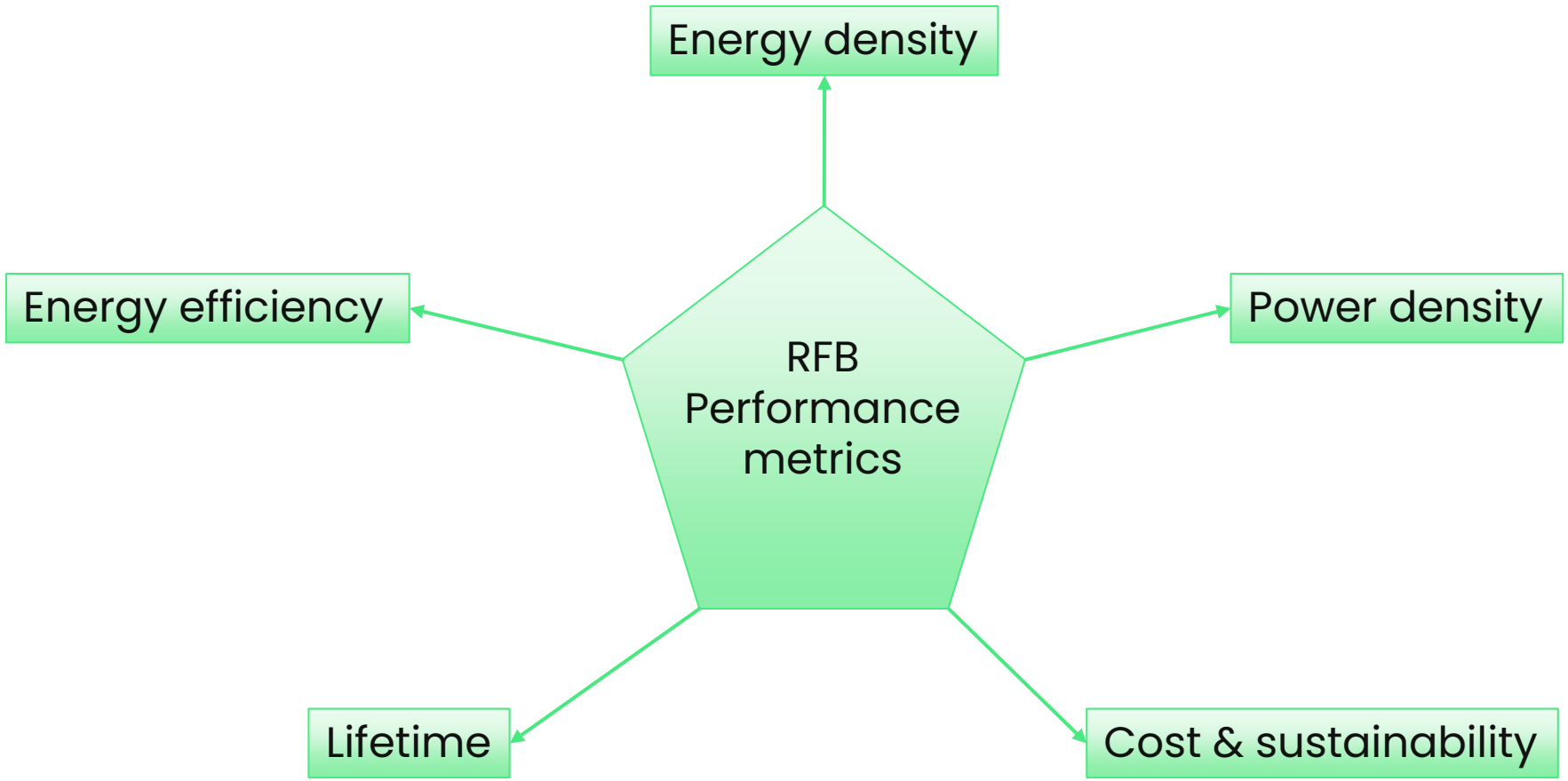


Power unit main components



Images from: Journal of electro-chemical society, 165 (5) A970-A1010 (2018)

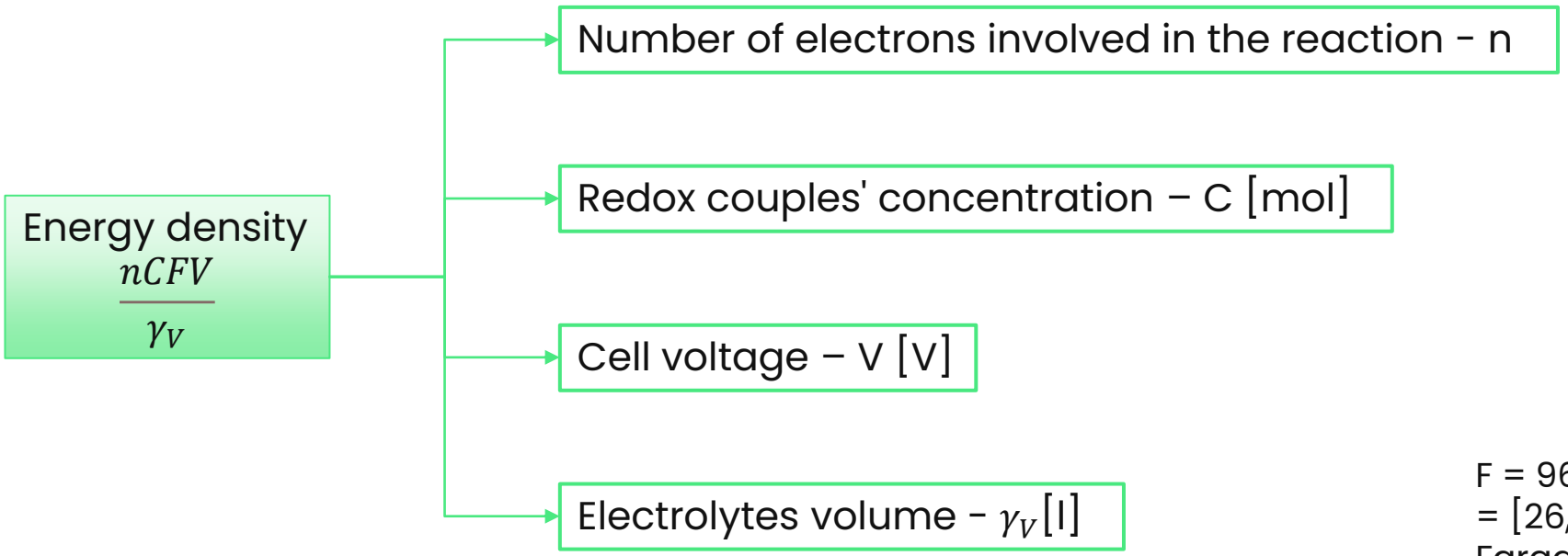
RFBS PERFORMANCE METRICS



RFBS PERFORMANCE METRICS

Energy density [Wh/l]

- RFB energy density depends on electrolyte properties
- Theoretical battery capacity depends on electrolyte volume
- GES theoretical energy density **>120 Wh/l**

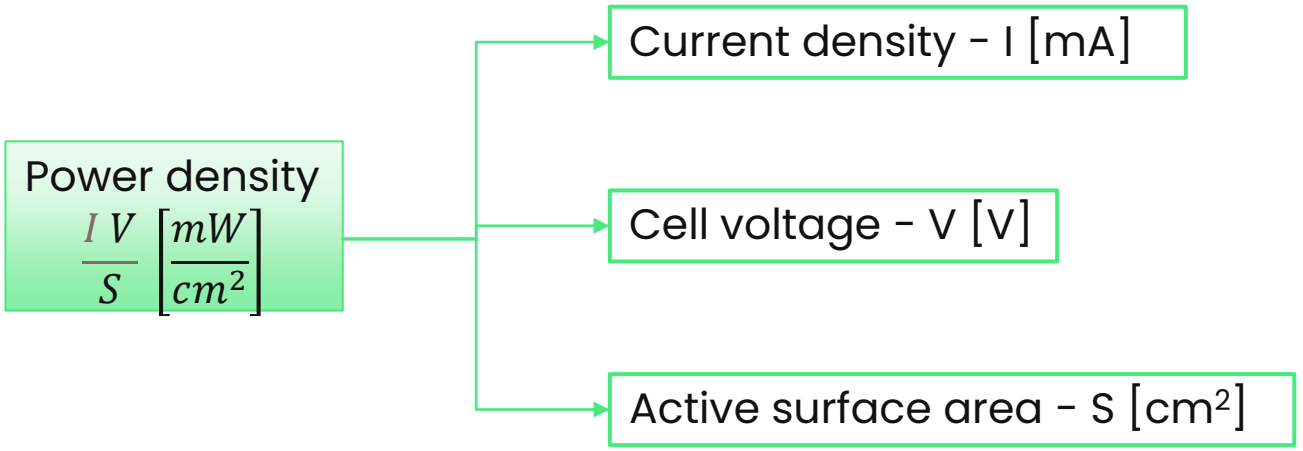


F = 96485 [C/mol]
= [26,8 Ah/mol]
Faraday's constant

RFBS PERFORMANCE METRICS

Power density [mW/cm²]

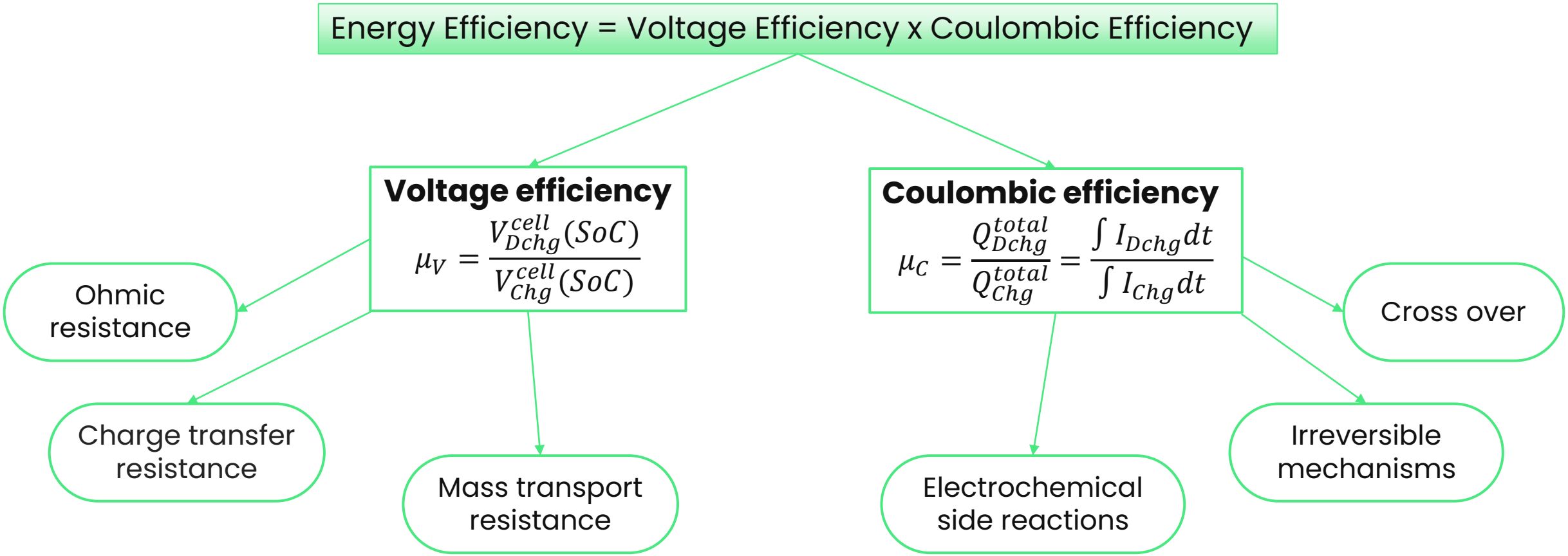
- RFB power density depends on cell components' properties, mainly electrodes.
- Power density can be tailored by tuning the dimensions of the electrochemical cell



RFBS PERFORMANCE METRICS

Energy Efficiency [%]

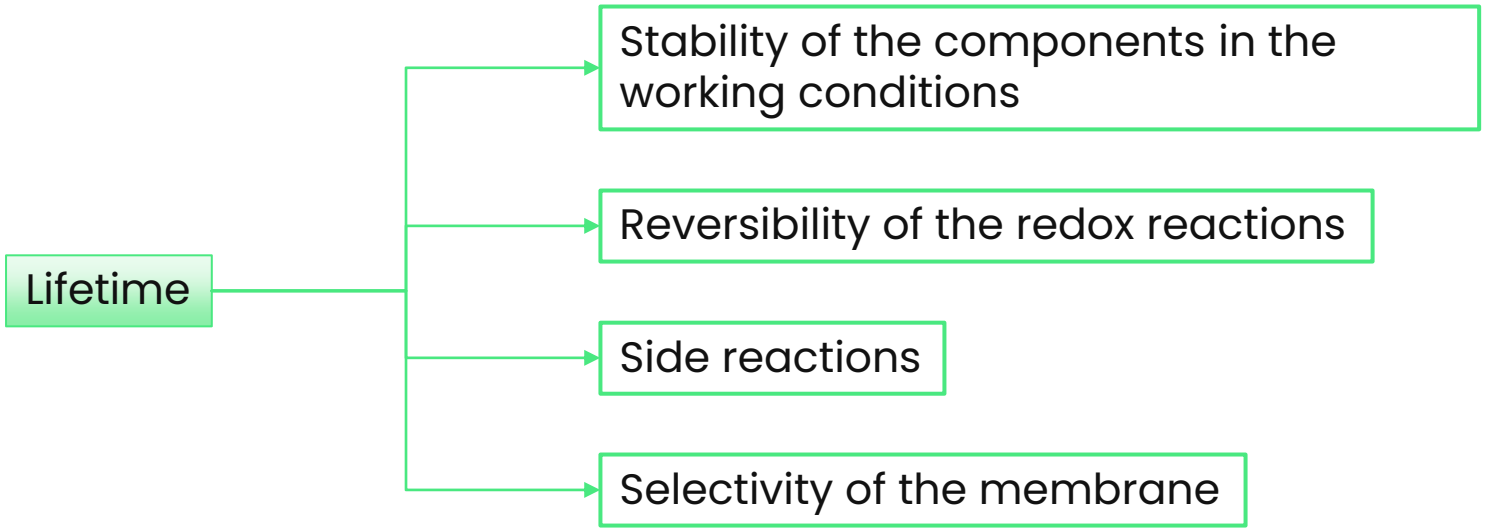
- GES target **>85%**



RFBS PERFORMANCE METRICS

Lifetime

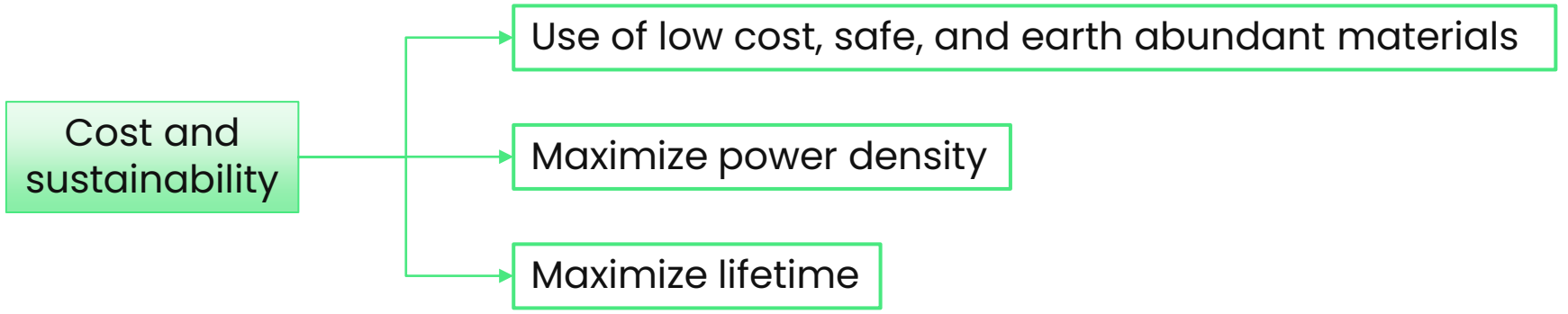
- GES target **>10 000 charge discharge cycles**



RFBS PERFORMANCE METRICS

Cost & sustainability

- Levelized cost of storage for long-duration stationary applications
  - Strategic Energy Technology Plan (SET Plan) target: 0.05 €/kWh/cycle
  - Green Energy Storage (GES) target: **0,02 €/kWh/cycle**
- GES target for sustainability: **< 10% of EU critical raw material in battery components**



GES HYBRID RFB PROPERTIES

GES technology is based on a hybrid system: hydrogen as anolyte and an aqueous catholyte.
These active materials were selected because they own a potentially interesting electrochemical performance.

HYDROGEN ANOLYTE:

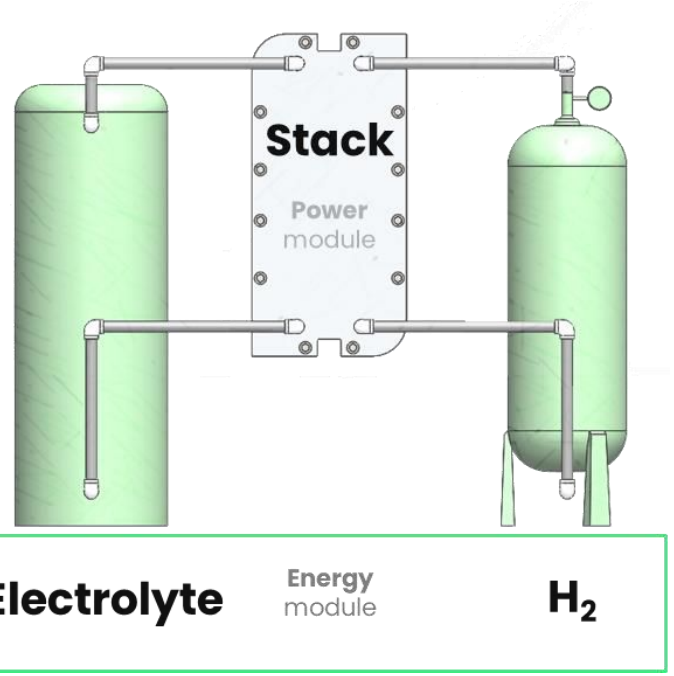
- Competitive electrochemical performances:
  - H_2 owns the lowest redox potential in aqueous electrolytes and the lowest overpotential in pH → Maximizes the cell voltage and efficiency
  - Current densities up to 1 A/cm^2 demonstrated in similar technologies → Maximizes the cell power density
- High worldwide investment to develop H_2 systems

GES AQUEOUS CATHOLYTE:

- Based on an abundant and economic active component (non-critical raw material)
- The electrolyte owns an acidic nature, it is non-toxic and non-corrosive
- Two PATENTS submitted on the catholyte chemistry

THEORETICAL VALUES AND KPIS:

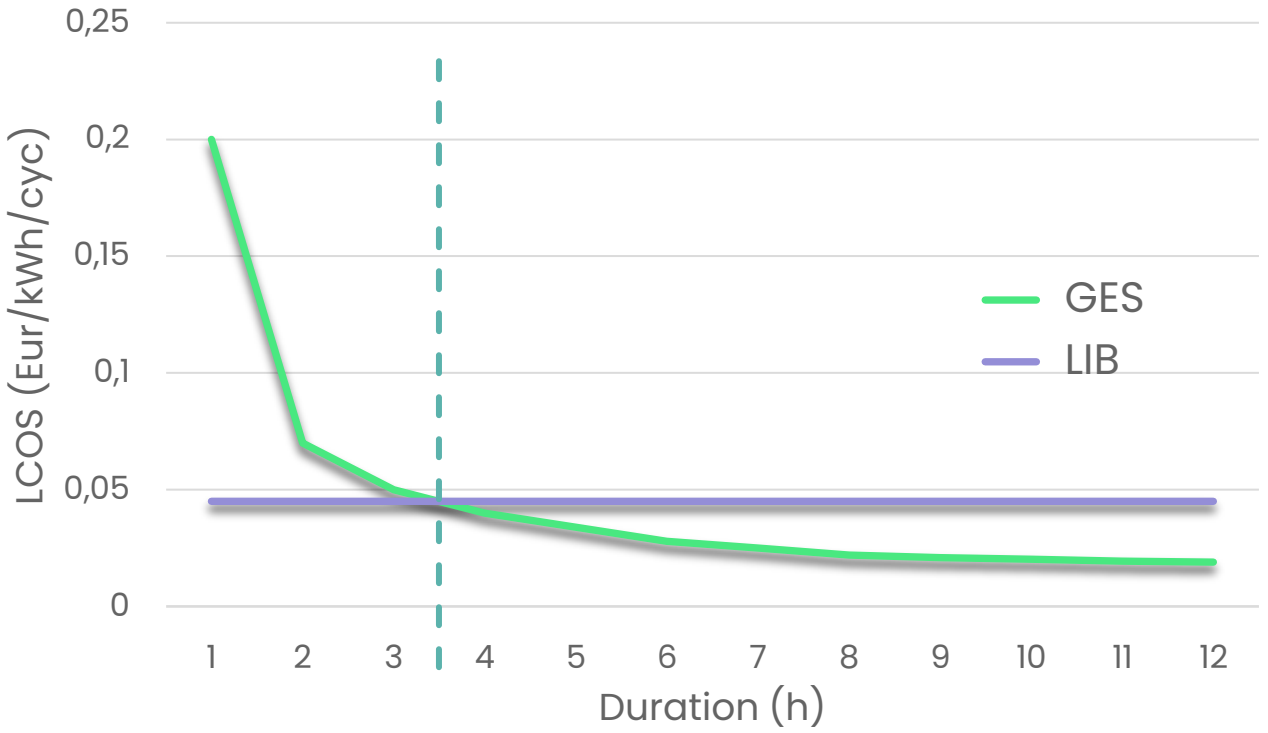
- Theoretical energy density >120Wh/l
- Energy efficiency >85%
- LCOS of 0,02 Eur/kWh/cyc in mass production



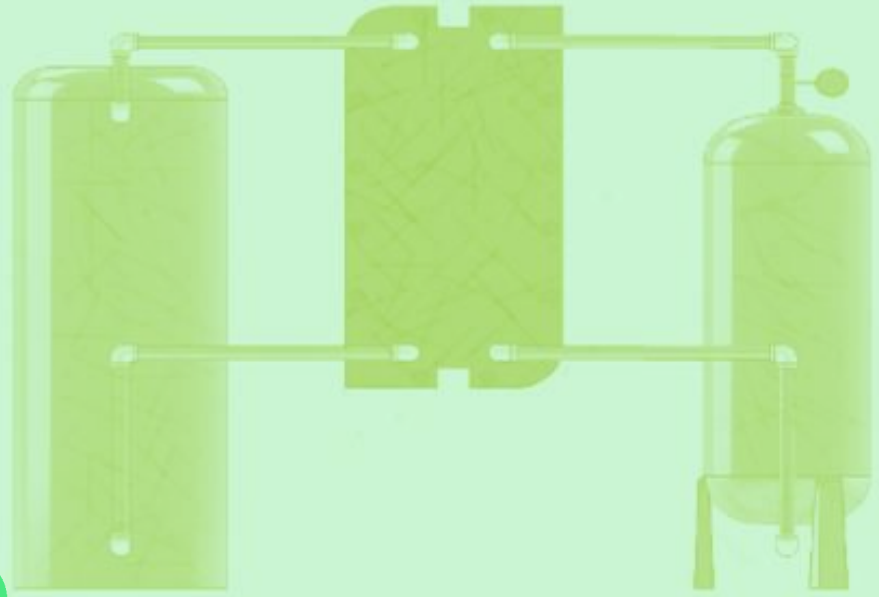
GES HYBRID RFB PROPERTIES

LCOS VS LIB:

- Thanks to energy power decoupling
- **From 3.5h** of duration, **GES system** is **more competitive** than Li-ion batteries.
- RFB LCOS estimation:
  - based on the techno-economic analysis: cost calculation of a 10 kW RFB battery with 10k cycles
  - The mass production forecast is based on the cost reduction estimated for similar H_2-RFB technologies.[1-3]
- LIB LCOS estimation:
  - LIB battery-pack price of $135/kWh and 3,000 cycles

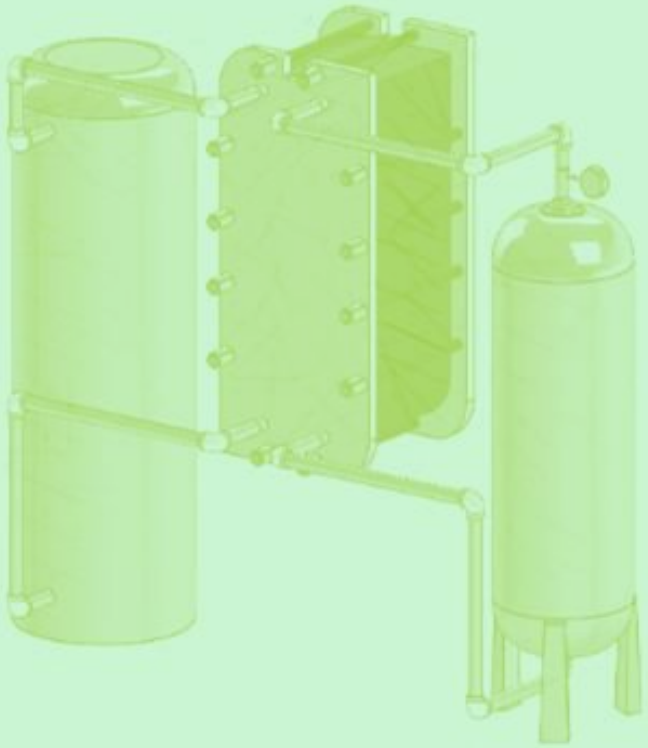


[1] Source: Y. A. Hugo. Techno-Economic Analysis of a Kilo-Watt Scale Hydrogen-Bromine Flow Battery System for Sustainable Energy Storage. *Processes* (**2020**) 8, 1492.
[2] Source: H. Zsiborács. Electricity Market Challenges of Photovoltaic and Energy Storage Technologies in the European Union: Regulatory Challenges and Responses. Appl. Sci. (2020), 10, 1472
[3]] Source: Ilja Pawel. The cost of storage - how to calculate the levelized cost of stored energy (LCOE) and applications to renewable energy generation. Energy Procedia 46 (2014) 68 – 77



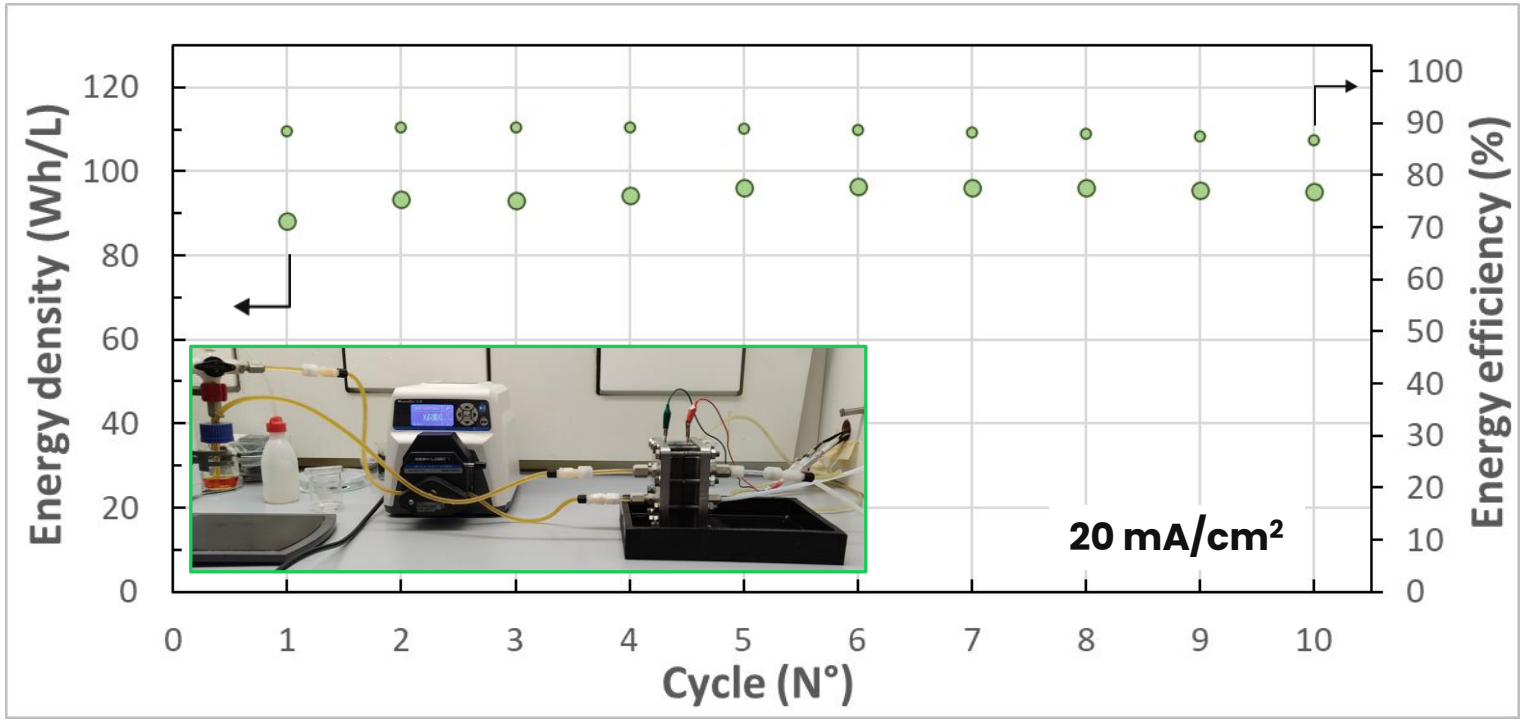
03

R&D ACTIVITIES



DEMONSTRATING THE COMPETITIVENESS OF H2-GES SYSTEM

The electrochemical performance of an 80 Ah/L electrolyte was monitored in a lab scale redox flow cell (25 cm^2 active area).



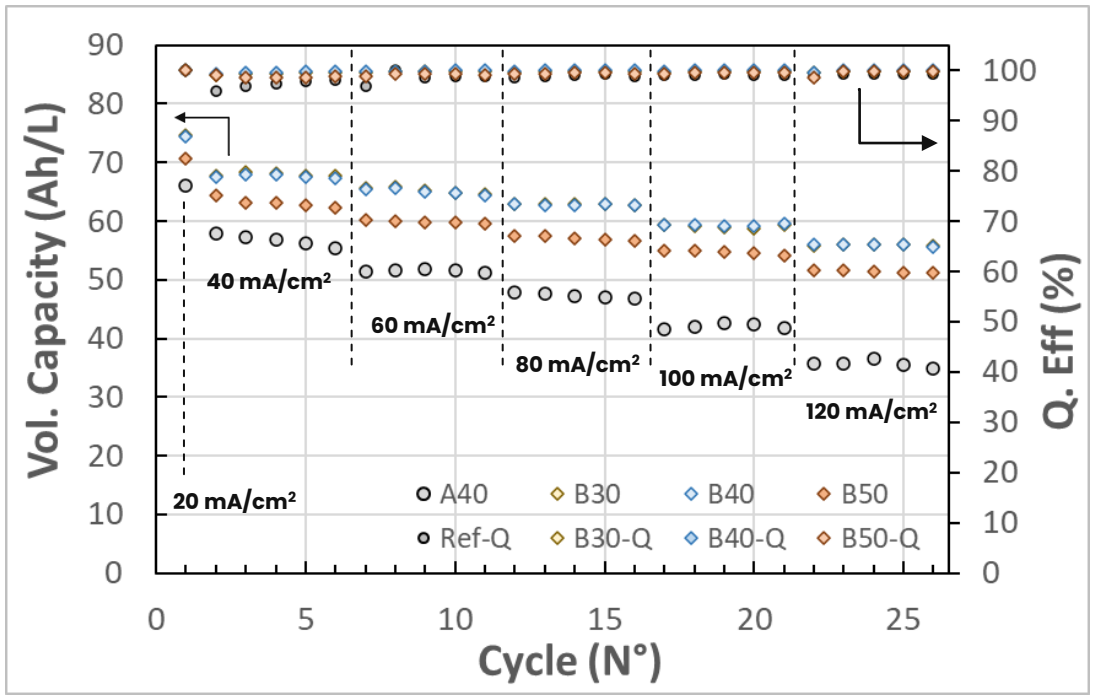
The system showed very promising electrochemical performance:

- Energy density: >90 Wh/L
- Energy efficiency: >85%

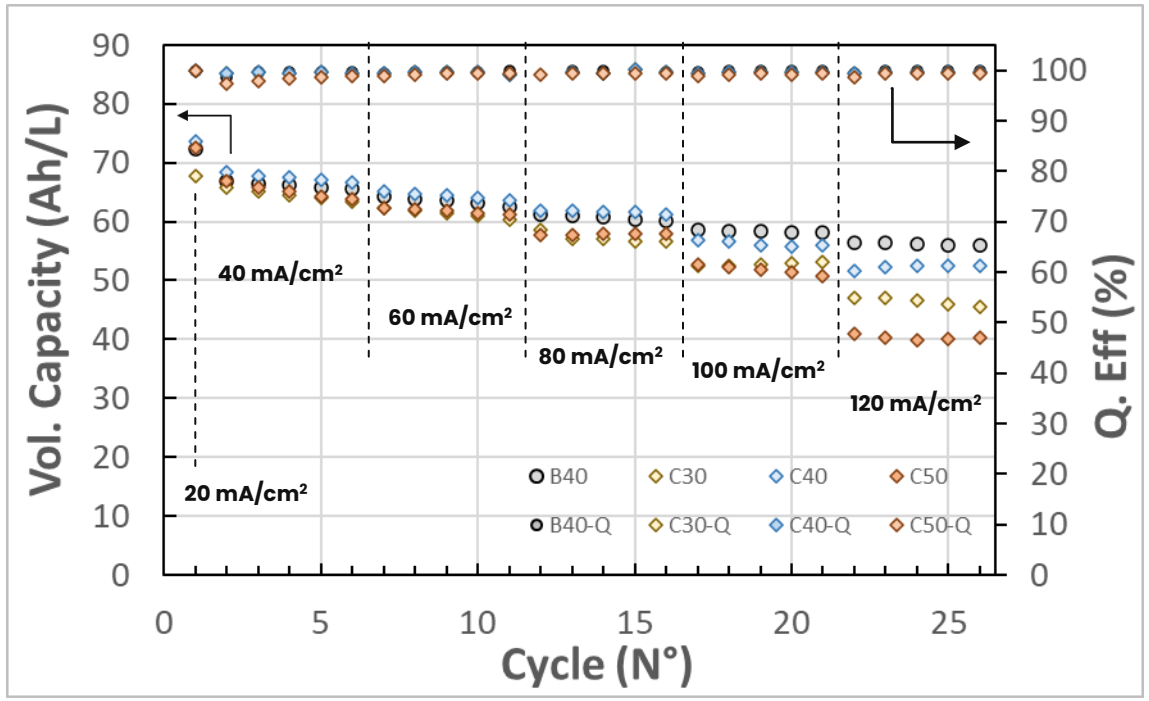
ELECTRODES' BENCHMARKING TO MAXIMIZE THE CURRENT DENSITY

Electrode benchmarking studies were carried out on an 80 Ah/L lab cell: the effect of the different electrodes (type and supplier) and compression grades (30, 40 and 50%) at different current densities was studied.

Electrodes A and B from SUPPLIER I



Best electrode from SUPPLIER I vs SUPPLIER II



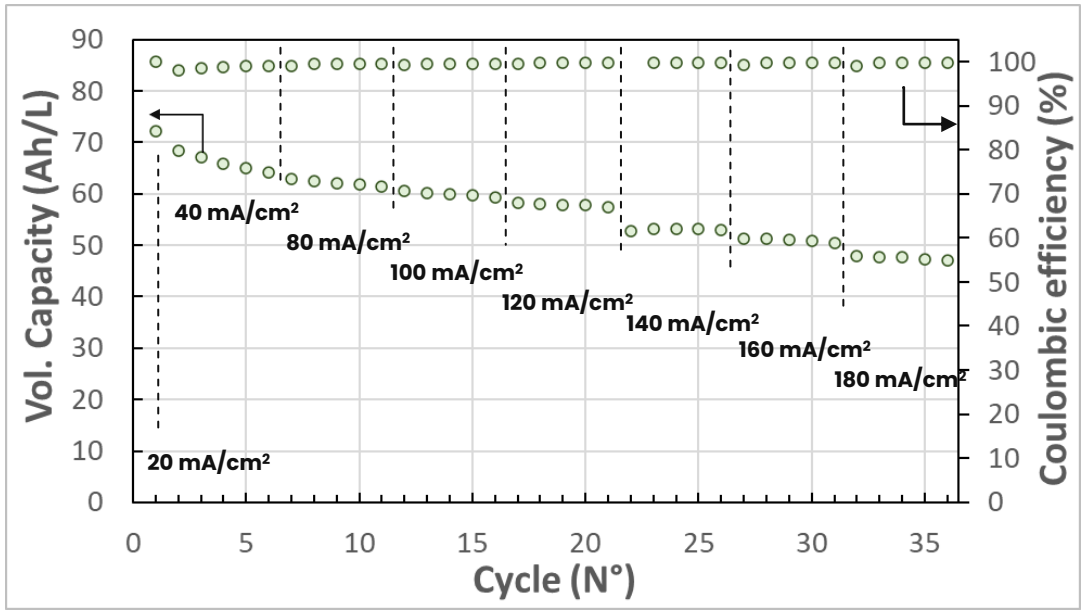
The results demonstrate that **current densities above 100 mA/cm² are feasible** by a proper selection of the electrode. Further studies are needed to maximize the delivered volumetric capacity.

A higher current density brings to a lower battery cost and a lower LCOS.

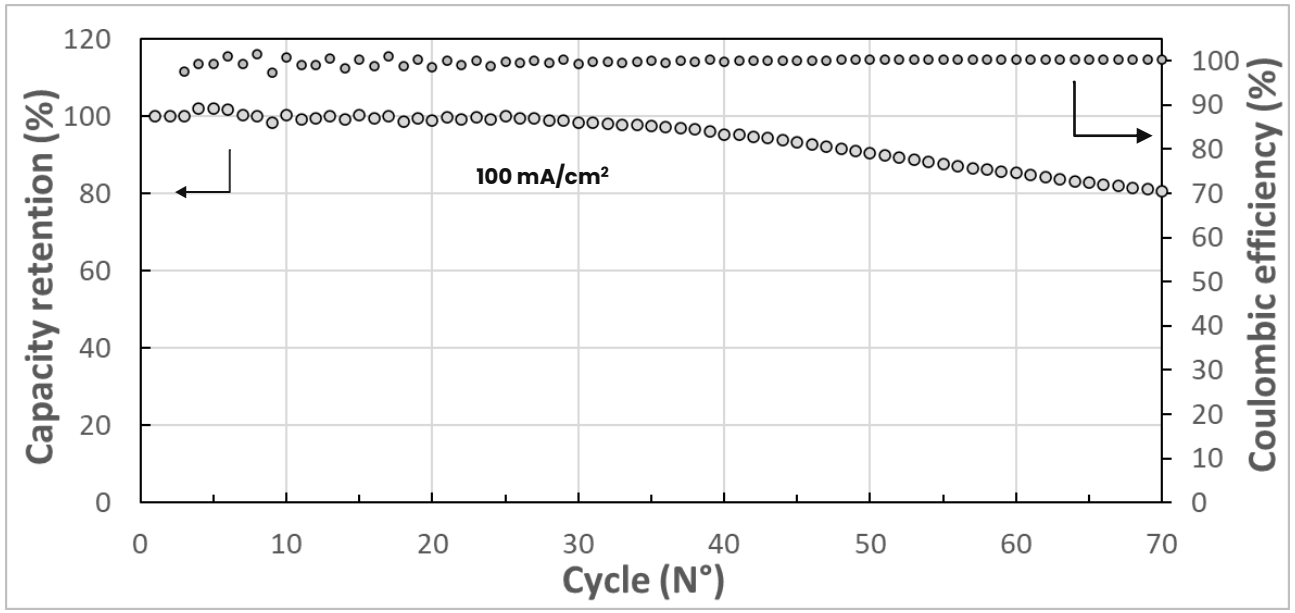
OPTIMIZING THE PERFORMANCE OF THE LAB CELL

Cell component benchmarking studies to boost the cell performance (current density and capacity retention).

Exploring the limits of the current density



First approach to cycle life assessment



- Demonstrated current densities in the range 20 to 180 mA/cm² → Power densities >0,2W/cm² seem feasible
- Demonstrated a volumetric capacity of 60 Ah/L at 100 mA/cm² → Energy densities >70 Wh/L at >0,12 W/cm² seem feasible
- Demonstrated high electrochemical reversibility (CE > 99%) and high energy efficiency (EE > 80%).
- Long cycle life performance under study.

04

TECHNOLOGY UPSCALING

UPSCALING ACTIVITIES

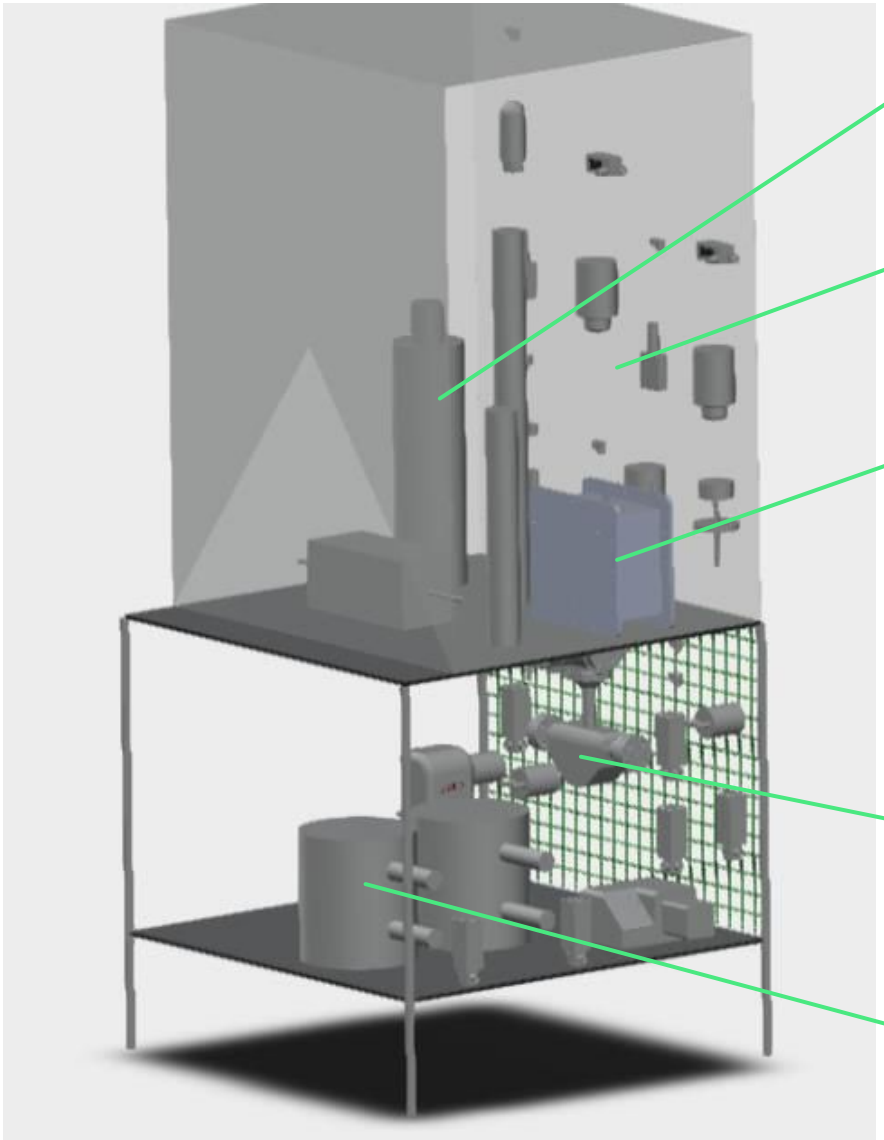
DE NORA

Holistic battery prototype characterization (battery and BoP performance) in safe conditions (ATEX standards)

Medium scale TB project executed in collaboration with De Nora.

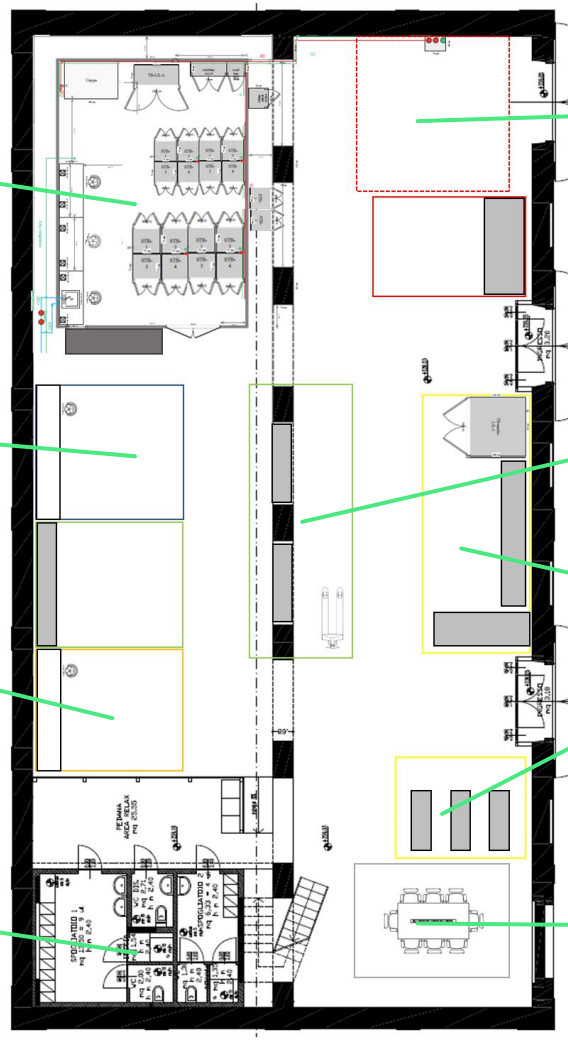
The project aims to:

- Design and manufacture 8 medium scale prototype characterization structures
- Integrate sensors into the balance-of plant for a full performance characterization
- Allow complete automation of the experiments: control and data acquisition system
- Test bench certification based on safety and ATEX standards



UPSCALING ACTIVITIES LAB

Lab setup to host fast prototyping and battery characterization and upscaling activities.



Chemical lab and battery testing room

Electrical and Electronics shop

Machine shop for fast prototyping

offices

Technical gases area

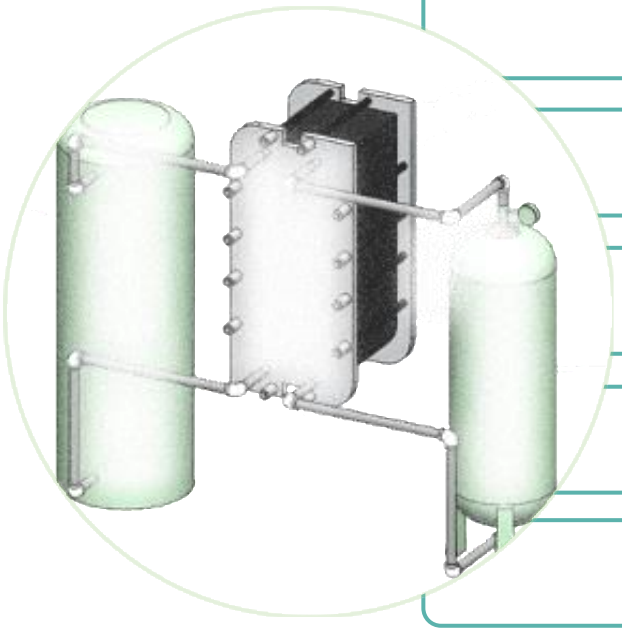
Battery components store

Store / prototypes showroom

Meeting room

DESIGN AND FABRICATION OF MEDIUM SCALE MINISTACK:

Due to the complexity of the test bench design, GES is collaborating with experts in the field



- Test-bench and power unit design
- Cell components development
- Software development (BMS)
- Electronic system development
- Cell design

GES IS RECRUITING EXPERTS IN DIFFERENT FIELDS like the above ones and others

OPEN POSITIONS (info@greenenergystorage.eu)

THANKS FOR YOUR ATTENTION

EMAIL

Contact details
info@greenenergystorage.eu

SOCIAL

https://it.linkedin.com/company/green-energy-storage

https://www.youtube.com/channel/UCLJQZ4s93ls400T4usRBxgA

European Commission

IPCEI BATTERIE 2_SA.55813_GREEN ENERGY STORAGE SRL

greenenergystorage.eu

VAT number 13308551004

July 28th, 2023