

All-iron flow battery for electrified airport operations

Andreas Podias, Alessio Lodge, Steven Wilkins | TNO Powertrains

TNO – Netherlands Organisation for Applied Scientific Research | Mobility & Built Environment Unit





TNO GENERAL INTRODUCTION



We are TNO

TNO is an independent not-for-profit research & innovation organization.

TNO connects people and knowledge to create innovations that sustainably enhance the competitiveness of businesses and the well-being of society.

TNO distinguishes itself through its:

- Independent position
- Multidisciplinary knowledge
- And cutting edge infrastructure / facilities



TNO: flywheel for innovation

Academia

Education
Publications



TNO innovation
for life

Making innovations market ready
TRL 4 > 7



Industry

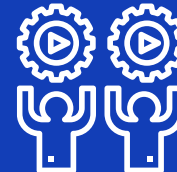
Sales
Profits



Developing
Fundamental knowledge



Developing
knowledge



Applying
knowledge



Knowledge
Exploitation

Different fields of expertise:



4.4

Client satisfaction

7.000+

Projects a year

3.000+

Companies

4000+

Workforce



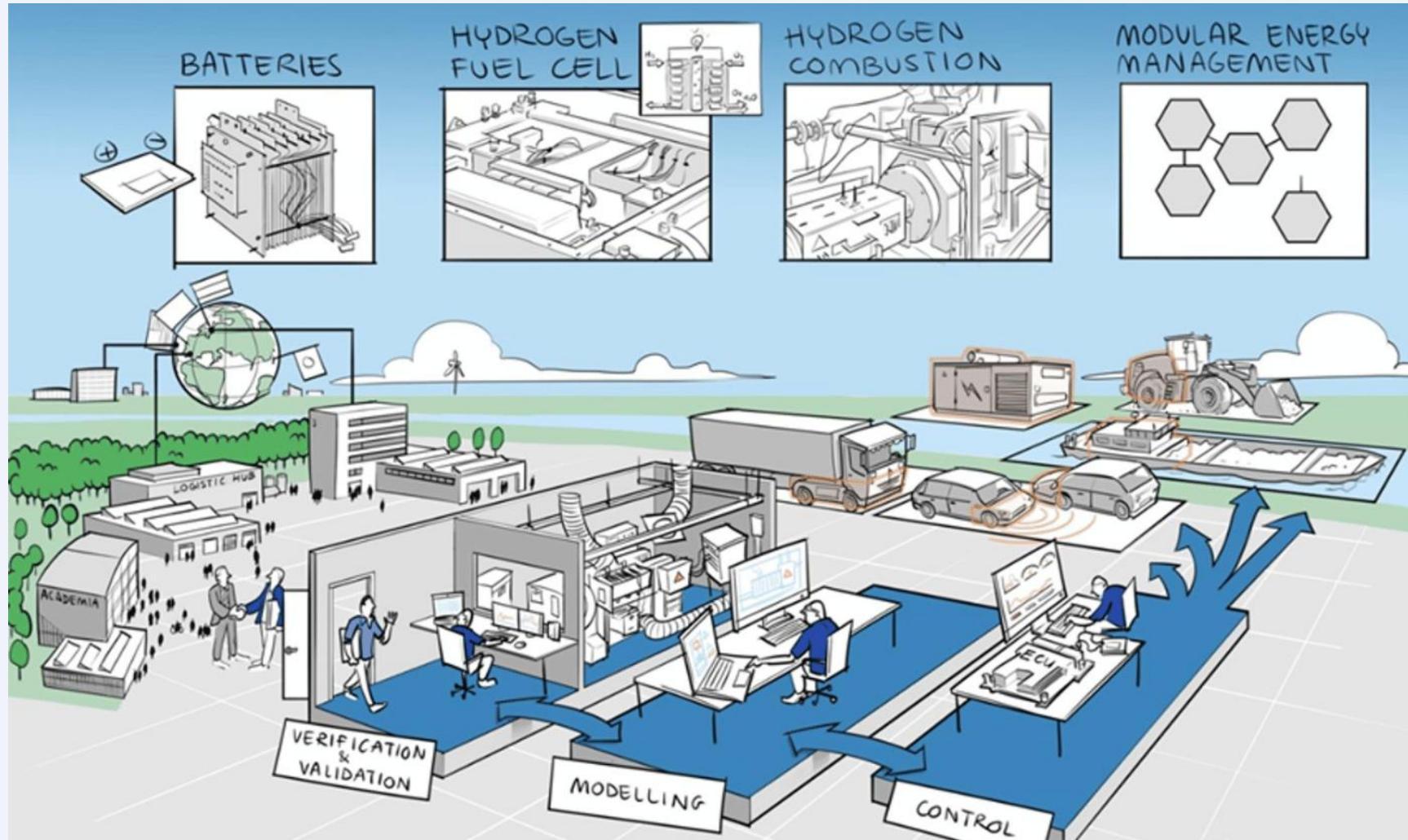
National Coverage

Highlighted some of our special facilities:

-  Building Innovation Lab (Delft)
-  Solar Lab (Petten & Eindhoven)
-  Castel milieulab (Utrecht)
-  Nanolab (Delft)
-  Accelerator Mass Spectrometer (Leiden)
-  Holst Center (Eindhoven)
-  Automotive Campus (Helmond)



Powertrains



Outline



Battery energy storage – why?



TULIPS



Zero emission airside operations demo



All-iron flow battery performance field data



All-iron flow battery performance model
→ Poster

Demonstrating lower polluting solutions for sustainable airports across Europe



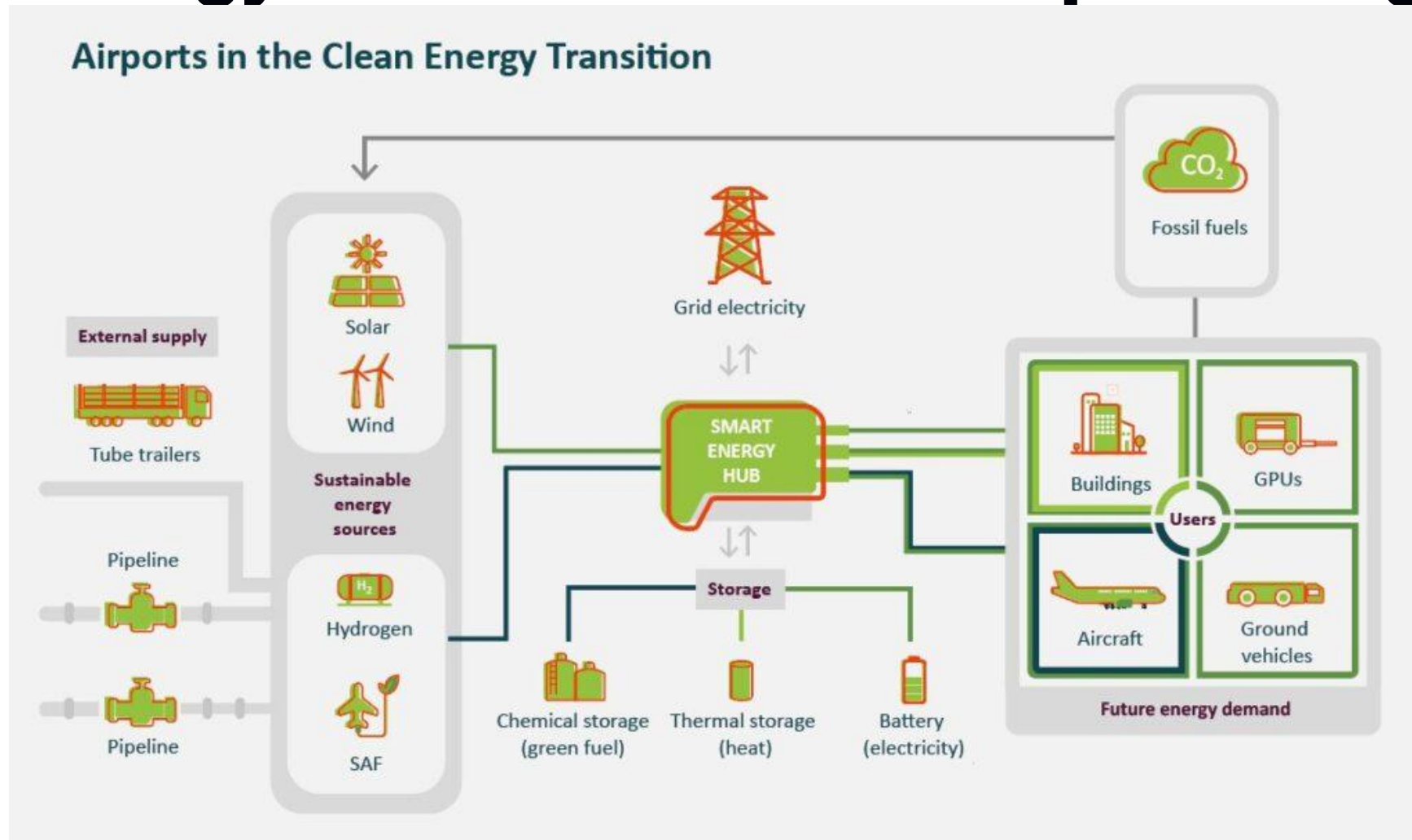
Funded by the European Union



Demonstrating lower polluting solutions for sustainable airports across Europe (TULIPS). [Online].

Available at: <https://tulips-greenairports.eu/about/> [Accessed: 7 February 2025].

Clean Energy Transition – Smart Airport Energy Hub



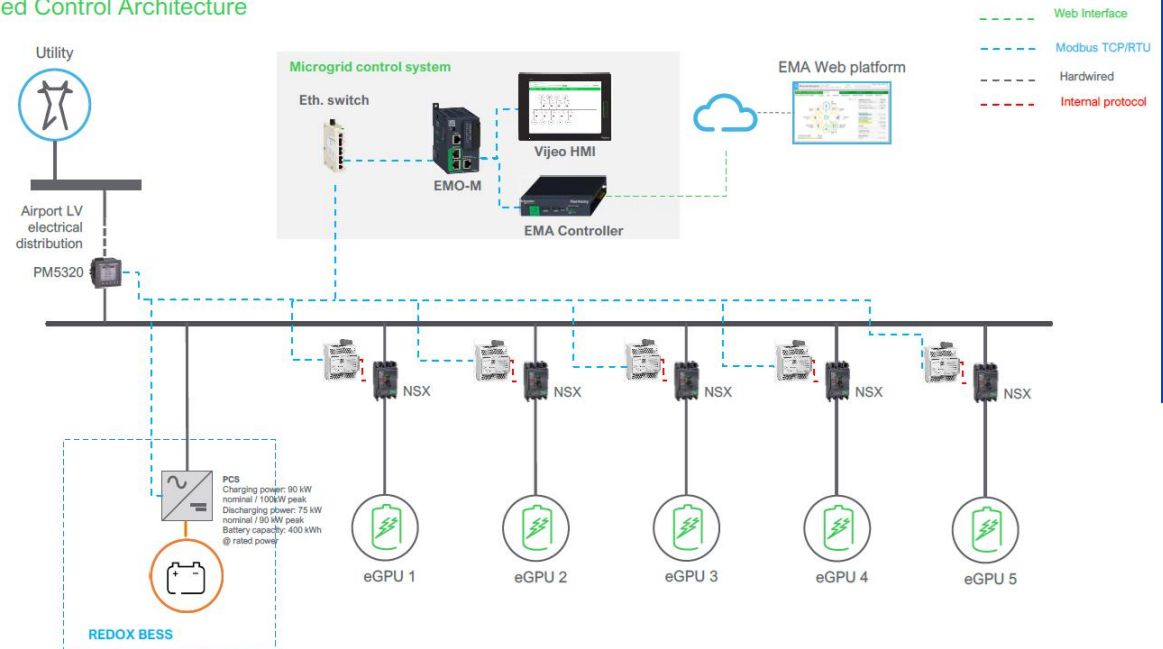
A. Kalkman, "Modelling and simulation of airports current and expected future scenarios" in TULIPS Progress Event: Accelerating Airports in the Clean Energy Transition, October 10, 2024. [Online] Available at: <https://tulips-greenairports.eu/tulips-progress-event-accelerating-airports-in-the-clean-energy-transition/> [Accessed: 7 February 2025].

Zero emission airside operations demo Platform A/B Schiphol Airport



Microgrid architecture composed of four layers:

Detailed Control Architecture



1/Energy & 2/Power Management Systems | 3/Distributed Energy Resources (DER) → PV – EV charging stations - All-iron flow battery system | 4/Electrical integration of the DER on Medium & Low Voltage systems

Source: Schneider Electric

All-iron flow battery specifications

Specifications

Features

| | |
|-----------------------|--|
| Nominal Power | 75kW |
| Peak Energy Capacity | 500kWh |
| Rated Energy Capacity | 400kWh |
| Standard DC Voltage | 880 VDC \pm 5% bi-polar |
| Optional AC Voltage | 400 VAC / 50 Hz, 3-phase or 480 VAC / 60 Hz, 3-phase |
| Response Time | < 1 second depending on operation mode |
| Module Cycle Life | > 20,000 cycles |
| Expected Life | 25-year design life |
| Controls | On-board battery management system: Modbus interface (SunSpec protocol) |
| Communication Options | 24/7 remote monitoring (TCP/Ethernet interface) |
| Certification | Inverter UL 1741-SA certified UL 1973, UL 9540, UL9540A, IP54, CE mark (EU version only) |

Mechanical

| | |
|----------------------|---|
| Footprint | 29.7 m ² or 320 ft ² ; Seismic rated (option) |
| Dimensions | 12.2 m x 2.4 m x 2.9 m (40 ft x 8 ft x 9.5 ft) |
| Max Transport Weight | 17,000 kg (37,479 lbs) |
| Max Operating Weight | 40,600 kg (89,508 lbs) |

Environmental

| | |
|---------------------|--|
| Battery | Iron, salt, water, aluminum, steel, recyclable plastics |
| Electrolyte | FeCl ₂ , KCl, H ₂ O; re-usable, recyclable |
| Ambient Temperature | 0°C to +40°C (+32°F to +104°F) rated operation |

| | |
|----------|--|
| Warranty | 1 year comprehensive defect warranty; 10-year warranty on core components, underwritten by Munich Re |
|----------|--|



Airside electricity demo

Specifications

Features

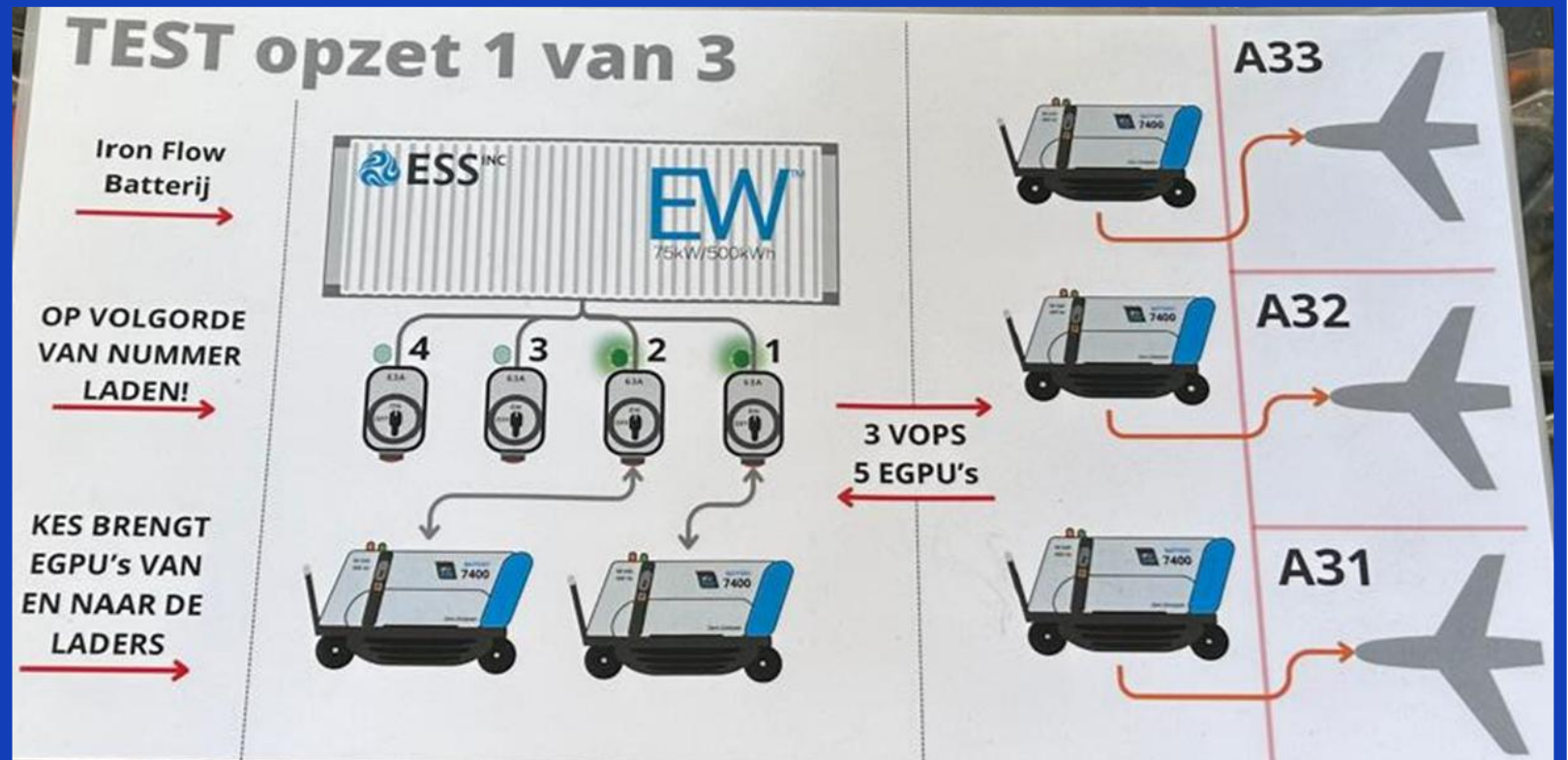
| | |
|-----------------------|--|
| Nominal Power | 75kW |
| Peak Energy Capacity | 500kWh |
| Rated Energy Capacity | 400kWh |
| Standard DC Voltage | 880 VDC ± 5% bi-polar |
| Optional AC Voltage | 400 VAC / 50 Hz, 3-phase or 480 VAC / 60 Hz, 3-phase |
| Response Time | < 1 second depending on operation mode |
| Module Cycle Life | > 20,000 cycles |
| Expected Life | 25-year design life |
| Controls | On-board battery management system: Modbus interface (SunSpec protocol) |
| Communication Options | 24/7 remote monitoring (TCP/Ethernet interface) |
| Certification | Inverter UL 1741-SA certified UL 1973, UL 9540, UL9540A, IP54, CE mark (EU version only) |

Mechanical

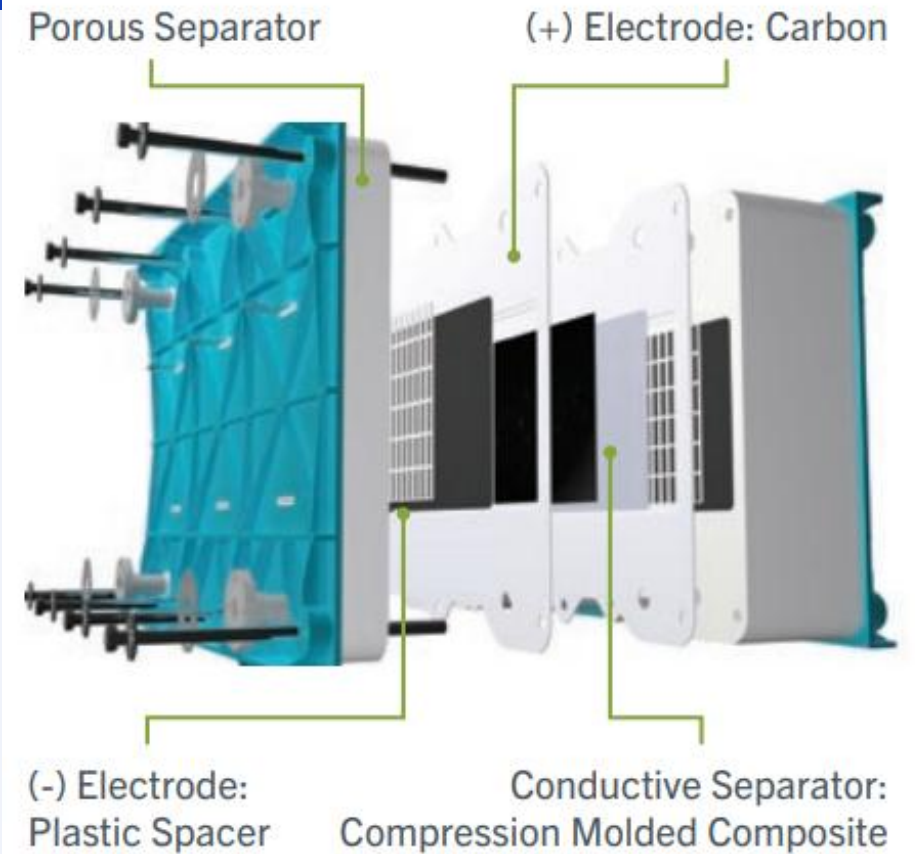
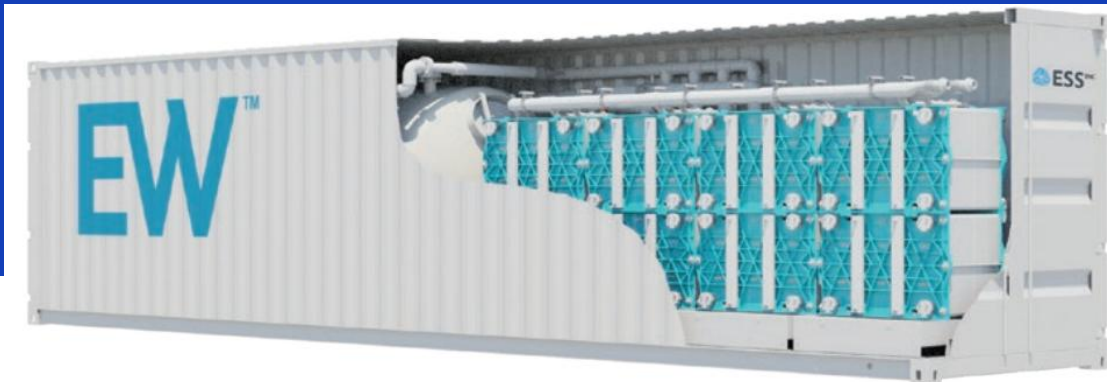
| | |
|----------------------|---|
| Footprint | 29.7 m ² or 320 ft ² ; Seismic rated (option) |
| Dimensions | 12.2 m x 2.4 m x 2.9 m (40 ft x 8 ft x 9.5 ft) |
| Max Transport Weight | 17,000 kg (37,479 lbs) |
| Max Operating Weight | 40,600 kg (89,508 lbs) |

Environmental

| | |
|---------------------|--|
| Battery | Iron, salt, water, aluminum, steel, recyclable plastics |
| Electrolyte | FeCl ₂ , KCl, H ₂ O; re-usable, recyclable |
| Ambient Temperature | 0°C to +40°C (+32°F to +104°F) rated operation |
| Warranty | 1 year comprehensive defect warranty; 10-year warranty on core components, underwritten by Munich Re |

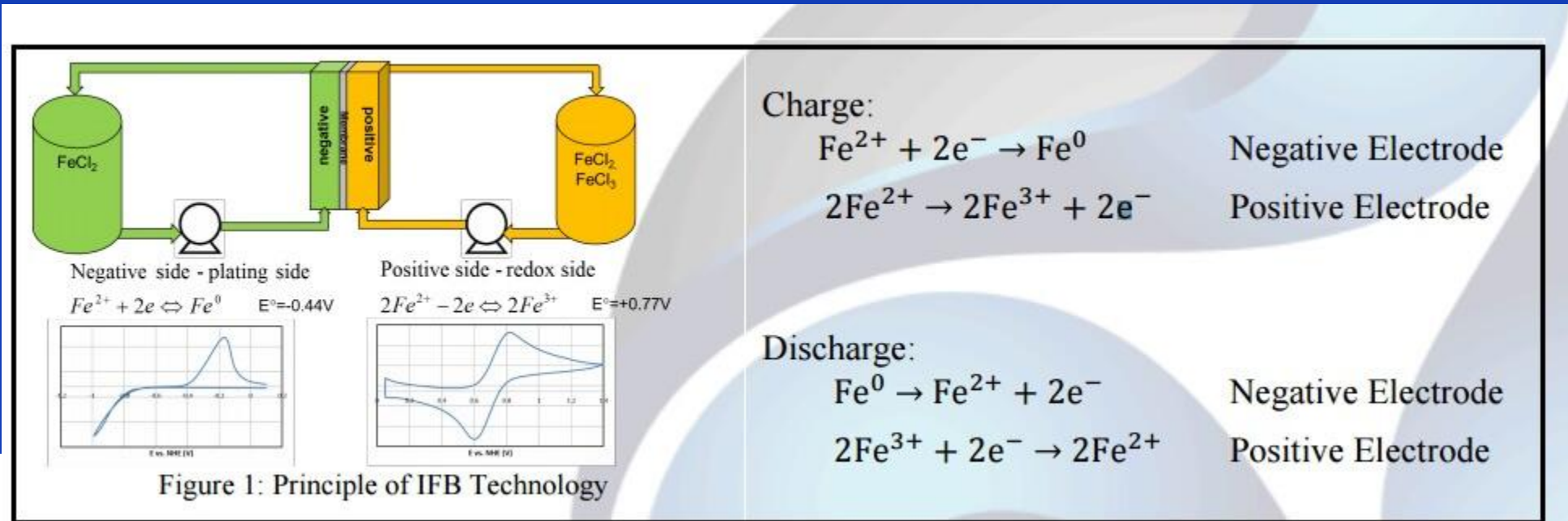


All-iron flow battery – Energy Warehouse™ (ESS Tech Inc.)



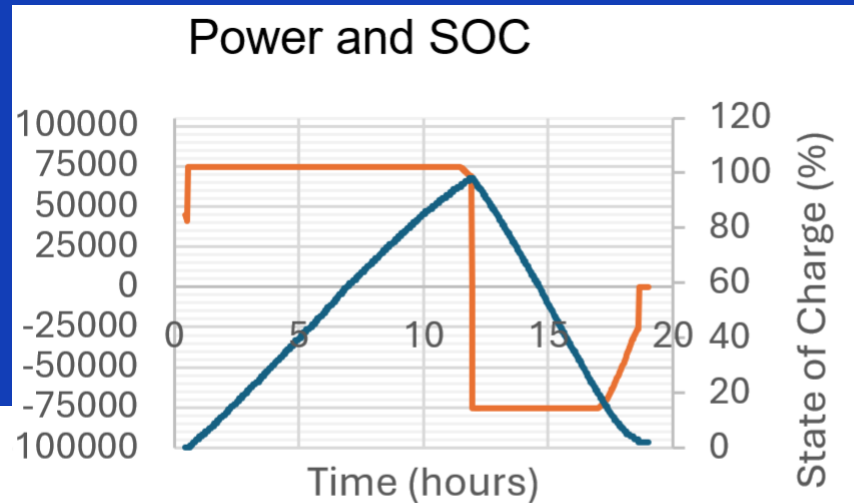
Source: [Iron Flow Chemistry](#) | ESS, Inc.

All-iron flow battery - Overview



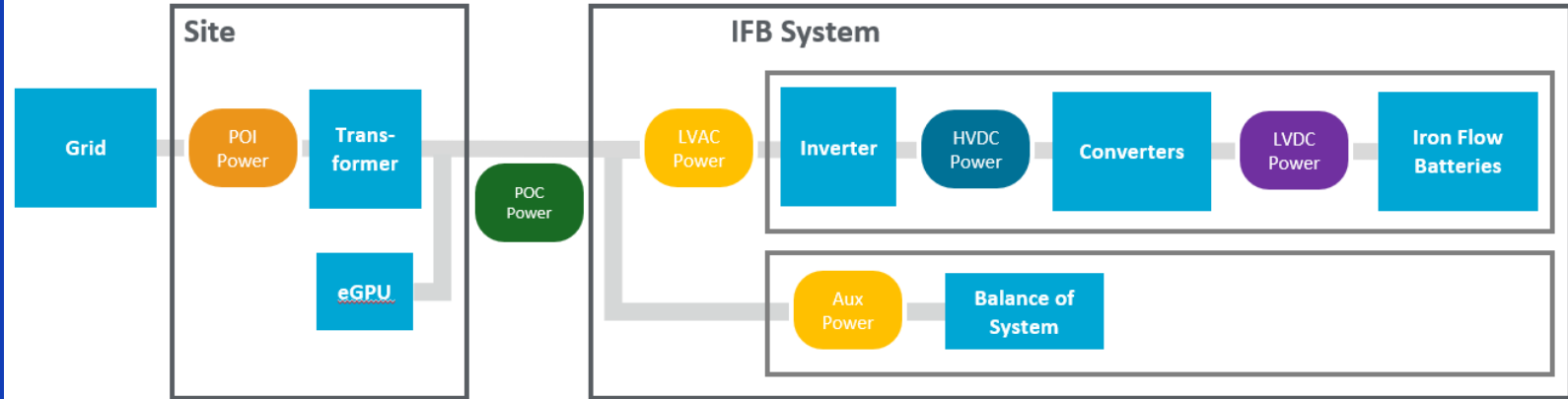
- The negative reaction involves plating of iron, always accompanied by the hydrogen side-reaction during charging $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$
- **Iron plating** on the negative electrode, **electrolyte crossover** through the membrane and **electrolyte rebalancing** (to manage electrolyte pH and SoC over operation) following proton loss via the negative electrode parasitic reaction are important aspects.
- Electrolyte health management (rebalancing) is based on capturing and transferring hydrogen from the negative electrode and combining it with excess ferric ions (Fe^{3+}) in the positive electrolyte.

Site Acceptance Test (SAT)



- SUNSPEC_ESS_DC_POWER_OUTPUT
- SUNSPEC_STATE_OF_CHARGE

AC Energy Warehouse Example Power Analysis



Power Locations (inside EW)

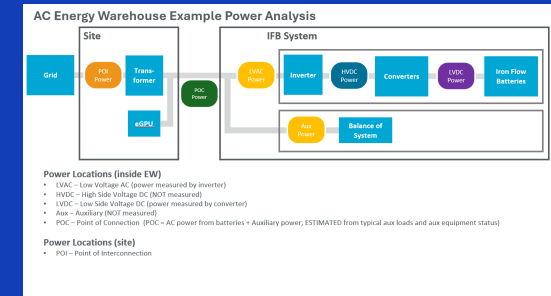
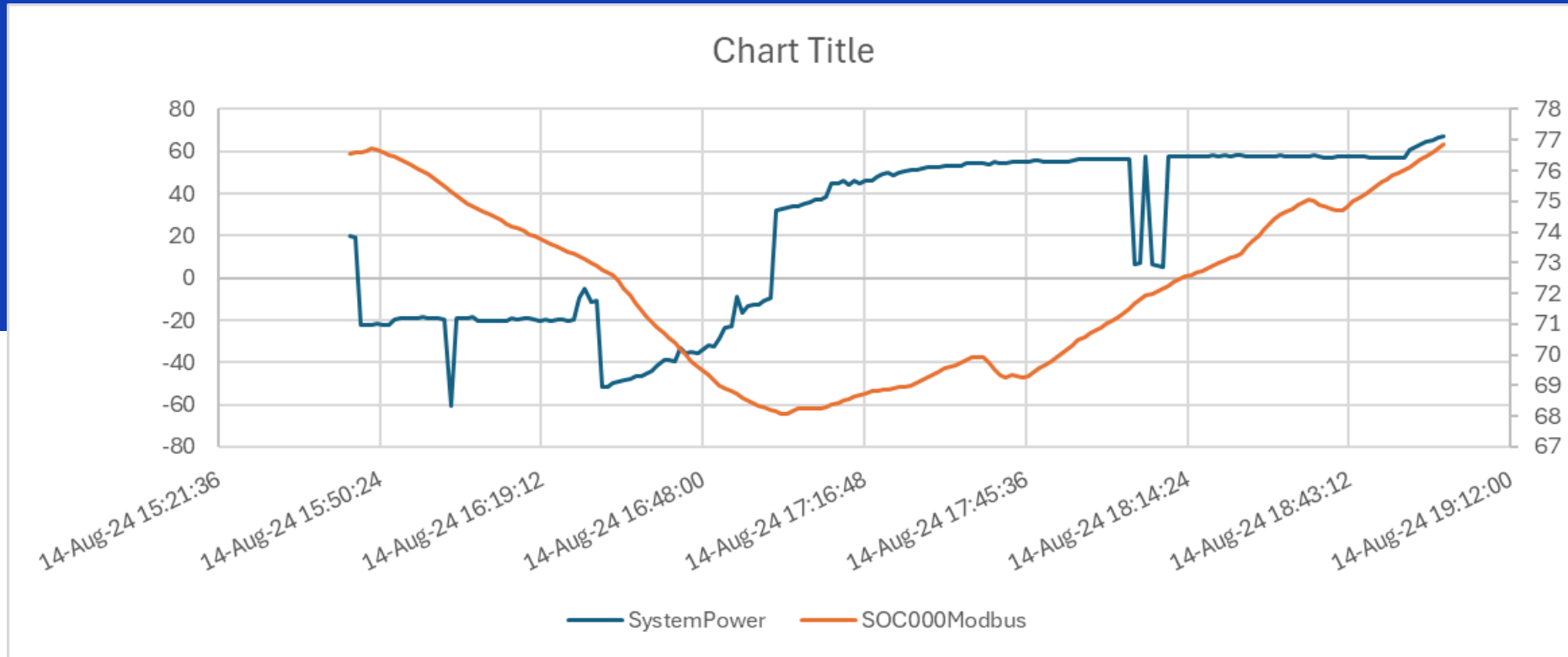
- LVAC – Low Voltage AC (power measured by inverter)
- HVDC – High Side Voltage DC (NOT measured)
- LVDC – Low Side Voltage DC (power measured by converter)
- Aux – Auxiliary (NOT measured)
- POC – Point of Connection (POC = AC power from batteries + Auxiliary power, ESTIMATED from typical aux loads and aux equipment status)

Power Locations (site)

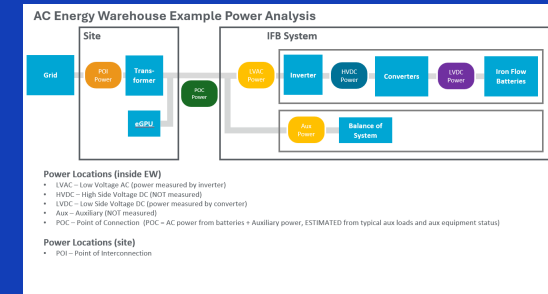
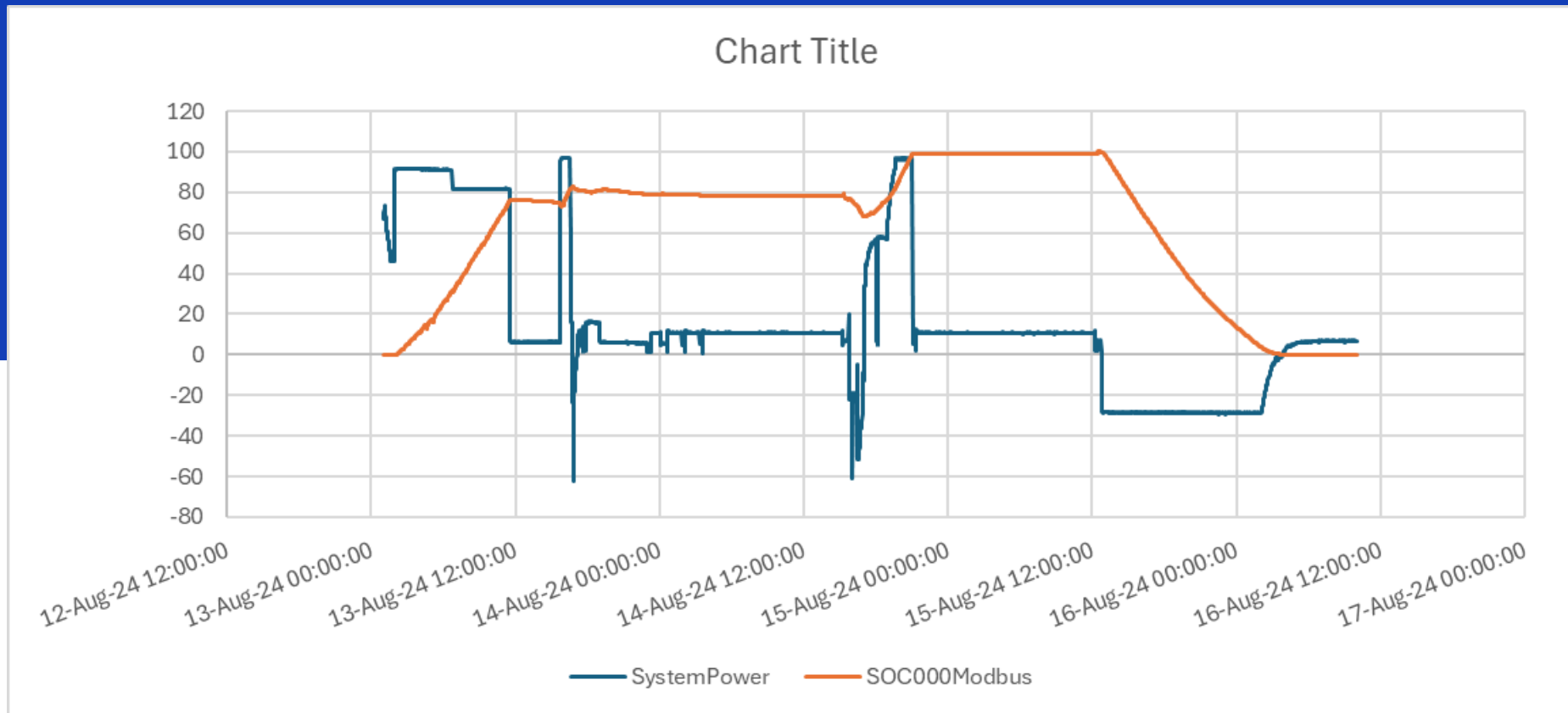
- POI – Point of Interconnection

*Personnal communication: Tj Mcdonald (ESS Tech Inc.)

All-iron flow battery – Performance over time (1/4)



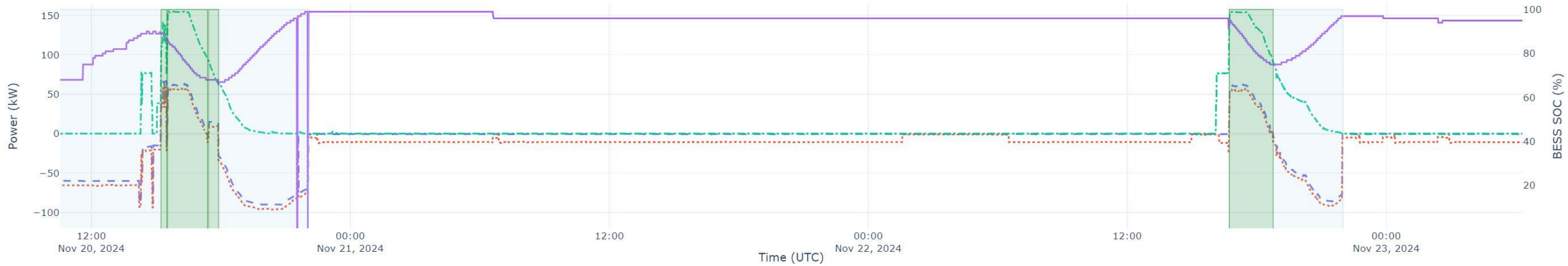
All-iron flow battery – Performance over time (2/4)



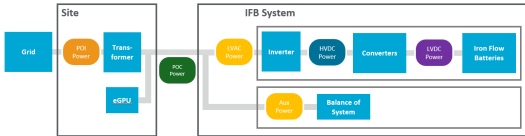
All-iron flow battery – Performance over time (3/4)

--- SUNSPEC ESS AC Power (kW)
 - - - BESS Electrical Power (kW)
 - - - eGPU Outlet Sum Power (kW)
 --- BESS SOC (%)
 --- Standby long/short
 --- Unoperational (no power control / standby)
 --- Power Control
 --- System Discharging
 --- System Charging

ESS & Site-Level Power vs Time



AC Energy Warehouse Example Power Analysis

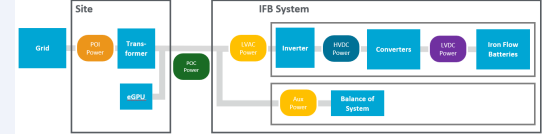


- Power Locations (inside EW)**
- LVAC – Low Voltage AC (power measured by inverter)
 - HVDC – High Side Voltage DC (NOT measured)
 - LVDC – Low Side Voltage DC (power measured by converter)
 - Aux – Auxiliary (NOT measured)
 - POC – Point of Connection (POC – AC power from batteries + Auxiliary power, ESTIMATED from typical aux loads and aux equipment status)

- Power Locations (site)**
- POC – Point of Interconnection

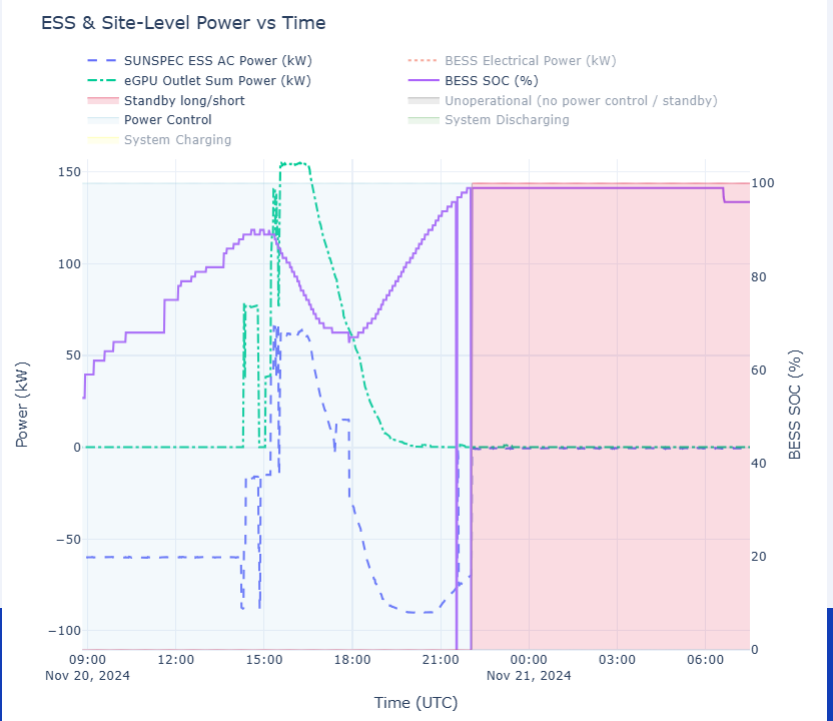
All-iron flow battery - Performance over time (4/4)

AC Energy Warehouse Example Power Analysis

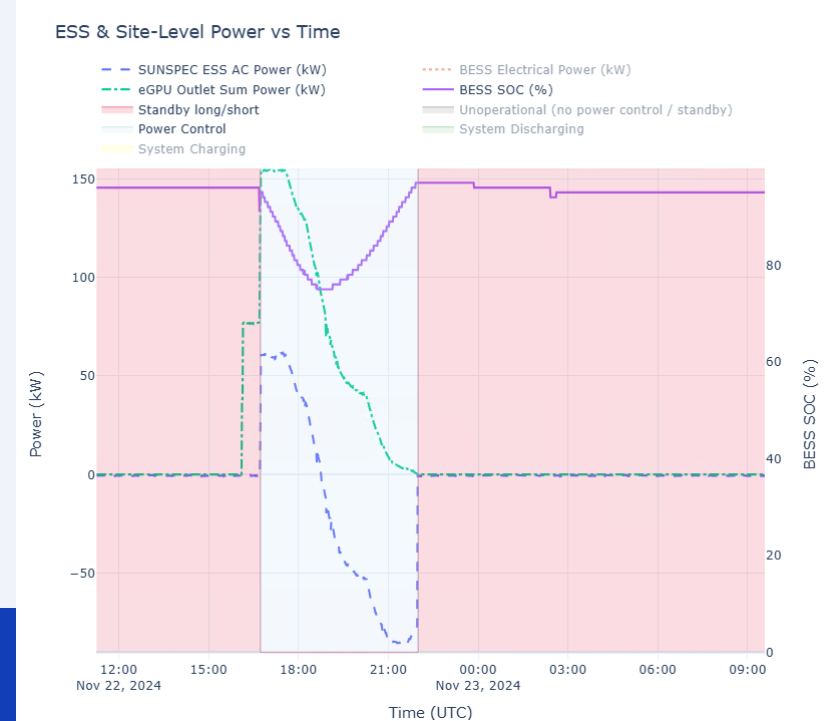


- Power Locations (inside EW)**
- LVAC - Low Voltage AC (power measured by inverter)
 - HVDC - High Side Voltage DC (NOT measured)
 - LVDC - Low Side Voltage DC (power measured by converter)
 - Aux - Auxiliary (NOT measured)
 - POC - Point of Connection (POC - AC power from batteries + Auxiliary power, ESTIMATED from typical aux loads and aux equipment status)
- Power Locations (site)**
- POI - Point of Interconnection

Roundtrip efficiency 51.68%



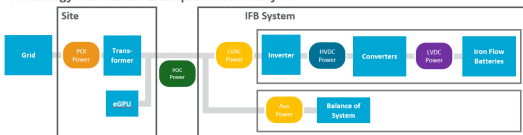
Roundtrip efficiency 48.05%



All-iron flow battery – Performance data summary example

| Start Date (Central European Time) | Discharge Duration (hrs) | Avg LVDC Discharge Power (kW) | Avg LVDC Charge Power (kW) | LVDC Energy Efficiency (%) | Avg POC Discharge Power (kW) | Avg POC Charge Power (kW) | POC Energy Efficiency (%) |
|------------------------------------|--------------------------|-------------------------------|----------------------------|----------------------------|------------------------------|---------------------------|---------------------------|
| 2024-03-21 10:45 | 0.5 | -36.9 | 73.5 | 62.5% | -18.6 | 95.6 | 23.1% |
| 2024-03-21 12:15 | 1.6 | -25.8 | 31.0 | 60.4% | -16.6 | 42.7 | 15.5% |
| 2024-08-14 15:45 | 1.2 | -33.9 | 43.2 | 53.3% | -25.6 | 51.4 | 31.4% |
| 2024-11-20 16:00 | 2.6 | -43.2 | 68.8 | 60.9% | -36.2 | 77.7 | 42.3% |
| 2024-11-22 17:30 | 2.0 | -47.7 | 53.6 | 60.1% | -40.8 | 61.9 | 42.1% |
| 2024-11-26 21:00 | 0.2 | -8.1 | 7.6 | 51.0% | -4.3 | 12.4 | 7.0% |
| 2024-12-05 21:00 | 0.3 | -12.6 | 8.5 | 59.6% | -7.4 | 21.6 | 9.5% |
| 2024-12-10 21:45 | 0.7 | -18.4 | 30.3 | 54.6% | -12.6 | 36.4 | 26.0% |
| 2024-12-20 19:00 | 0.4 | -17.4 | 29.7 | 36.3% | -11.4 | 35.4 | 16.0% |

AC Energy Warehouse Example Power Analysis



Power Locations (inside EW)

- LVAC – Low Voltage AC (power measured by inverter)
- HVDC – High Side Voltage DC (NOT measured)
- LVDC – Low Side Voltage DC (power measured by converter)
- Aux – Auxiliary (NOT measured)
- POC – Point of Connection; IPDC – AC power from batteries + Auxiliary power, ESTIMATED from typical aux loads and aux equipment status)

Power Locations (site)

- POC – Point of Interconnection

Concluding remarks

- Safety and low-cost active materials, utilising earth-abundant iron, salt and water made all-iron FBs an attractive solution for RSG towards safe & sustainable airport operations and reducing the carbon footprint and air pollution.
- The airside electricity demo operated for almost a year; more data are needed, however, to evaluate key metrics for performance, lifetime, availability of the specific BESS.



Acknowledgements

- Federico Ribatti, Camiel Beckers, Roel de Groot, Floris van de Beek, Arie Kalkman (TNO)
- Wesley Teuuwisse (Royal Schiphol Group)
- Ronald Richardson, Adam Wasserzug, May Albadr, TJ Mcdonald, Ben Heng, Brian Lisiecki (ESS Tech Inc.)
- Jasper Poortvliet (KESS)
- Sander de Jong (Schneider Electric)

This work has been conducted in the framework of the TULIPS project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101036996.



**Funded by
the European Union**



Thank you for your attention!

TNO innovation
for life

All-iron flow battery for electrified airport operations

Andreas Podias, Alessio Lodge, Steven Wilkins | TNO Powertrains

andreas.podias@tno.nl

alessio.lodge@tno.nl

steven.wilkins@tno.nl

