Barriers to the development and diffusion of redox flow batteries: A functional analysis of the global innovation system

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Introduction

- There is a growing need in development of energy storage systems that are crucial for constant, resilient and secure energy supply.
- Flow batteries are gaining increased attention as promising energy storage devices, but the flow battery industry remains scattered.
- This study applies **the technological innovation system (TIS) framework** to identify the barriers to the development and diffusion of flow batteries.

Methods and data

- The study is based on the qualitative data from **36 semi-structured interviews** with different actors of the flow batteries innovation system (See Table 1).
- The interviews provided insights on the current state of innovations, structure, challenges, drivers, interactions and future visions of the innovation system.

Table 1. Overview of interviewees across perspectives and regions

Interview perspective	Region and number of interviewees
Battery producers	Africa (1); Europe (9); Australia (1); Asia (3); North America (1)
R&D	Europe (6); North America (1)
Investors	Europe (2); North America (2)
Supliers	Europe (3); Australia (1); Asia (1); North America (4)
Policymakers	Europe (1)

Flow batteries innovation system analysis

The technological innovation system (TIS) framework offers an approach to analyse the dynamic interactions and institutional arrangements shaping innovation processes within a specific technological field through 6 key processes, so-called system functions that have a direct and immediate impact on the development, diffusion and use of new technologies: **(1) knowledge development & diffusion, (2) entrepreneurial experimentation**, **(3) influence on the direction of search**; **(4) legitimation**, **(5) resource mobilization,** and **(6) market formation** [1, 2].

Lack of large-scale demonstrations impedes technology legitimation.

Lack of large-scale pilots and demonstrations hinders development of 'knowledge-by-doing'.

Legitimacy influences actors' expectations and strategies.

Lack of trust in technology does not allow demand growth.

Knowledge development & diffusion

- Strong commitment of producers, suppliers, researchers in knowledge development
- Strong cooperation in knowledge creation
- Lack of knowledge and experience on systems scaling, design, manufacturing and operating at large scale
- Weak knowledge sharing by producers hinders innovation system development

Entrepreneurial experimentation

- Experimentation with commercial deployments for niche applications and markets
- Variety of electrolyte options are explored
- Lack of pilots and commercial deployments on larger scales
- Building large scale demonstrations requires a lot of resources

Influence on the direction of search

- Common vision on the need in flow batteries to support shift to renewable energy
- Anticipation of growing demand for flow batteries
- Promising electrolyte availability motivates further developments
- Competition from other energy storage types preventing new players' entrances

Legitimation

- Significant consensus of producers and suppliers on the prominent role of flow batteries for energy storage
- Legitimation based on Li-ion concerns: flammability and long-term storage capability
- Weak legitimation of VFB in the EU
- Technology not yet trusted enough by investors or potential users

Market formation

- Sufficient basic knowledge of customers on the technology
- No 'nursing market' for long duration storage flow batteries
- Lack of demand for long duration storage connected to current renewables penetration rate
- Lack of market incentives towards long duration storage adoption

Resource mobilisation

- Public funding is available (e.g. in the EU, the US) but requires effort to secure
- PhD fundings available globally
- Lack of private investment, particularly for the earlier technology development stages
- Lack of targeted funding for flow batteries technology

Weak resource mobilisation challenges pilots and demonstration plants development.

Lack of technology legitimacy hinders resource mobilization.

Conclusion and outlook

1. Pilots and demonstration plants are crucial for further development of knowledge and scaling up production. This, in turn, requires stronger resource mobilisation.
2. Although there is a shared consensus on the need for long term energy storage, there is not enough demand for it yet.
3. Legitimacy should be further strengthened by proving the technology's functioning in specific applications, as well as by forming stronger advocacy coalitions.

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