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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Nikita Akhmetov

PhD Program: Materials Science and Engineering

Title of Thesis: Development of lithium-conducting polymer-ceramic membranes for lithium-metal hybrid flow batteries

Supervisor: Professor Keith Stevenson

Name of the Reviewer: Atif Alzahrani

I confirm the absence of any conflict of interest.	**Date: 29-09-2023**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- **Brief evaluation of the thesis quality and overall structure of the dissertation.**

The thesis demonstrates a strong organizational framework, beginning with an introduction to the fundamentals of energy storage and its historical context. It then explores various types of energy storage, specifically focusing on the different classifications of redox flow batteries. Afterwards, it extensively explores the intricacies of redox flow battery membranes, encompassing their methods of testing and characterization. Following this, the thesis provides a comprehensive account of the experimental procedures involved in synthesizing fillers and setting up the testing apparatus. It further focuses on optimizing the fabricated membrane, demonstrating its effectiveness, and concludes with insightful remarks and a forward-looking perspective.

- **The relevance of the topic of dissertation work to its actual content**

The thesis's content holds significant relevance to the topic of developing lithium-conducting polymer-ceramic membranes for lithium-metal hybrid flow batteries. In summary, Nikita has successfully optimized the membrane fabrication process, which is a non-trivial task, and applied it to the promising field of lithium-metal hybrid flow batteries.

- **The relevance of the methods used in the dissertation**

The methods employed in the thesis are integral and pertinent for assessing the developed electrolyte. These methods encompass various physicochemical techniques to examine the physical properties, structural features, and chemical characteristics. Additionally, a diverse array of electrochemical methods, including Electrochemical Impedance Spectroscopy (EIS), are utilized to investigate the ionic conductivity and electrochemical performance of the membrane under both static and dynamic conditions.

- **The scientific significance of the results obtained and their compliance with the international level and current state of the art**

The field of energy storage plays a pivotal role in advancing decarbonization efforts within energy systems, and the selection of redox flow batteries or hybrid variants is a critical factor for stationary applications, enabling increased integration of renewable energy sources. Consequently, the development of effective solid electrolytes for hybrid redox flow batteries represents a cutting-edge research topic within the realm of energy storage.

- **The relevance of the obtained results to applications (if applicable)**

Nikita's work focuses on addressing the pressing need for stationary energy storage applications, which are crucial technologies for the decarbonization of the electricity sector. As a result, there exists a strong connection between Nikita's research and the practical application of stationary energy storage.

- **The quality of publications**

Nikita has made significant contributions as an author and co-author of five influential journal papers, with an average impact of 9. Notably, Nikita took the lead as the first author in two of these papers, which achieved an average impact of 11. What I find admirable is Nikita's ability to spearhead publications with higher impact and consistently incorporate his personal impact into each publication, demonstrating a commendable practice.

- **The summary of issues to be addressed before/during the thesis defense**

Nikita has made remarkable contributions to the advancement of composite electrolyte fabrication and its application in hybrid redox flow batteries, and I thoroughly enjoyed reading the thesis. While there are minor English editing issues, I would like to offer the following suggestions and inquiries:

1. In Figure 4.1, the current density is stated as 0.1 mA/cm2. It would be beneficial to clarify whether this same current density was applied for the redox flow battery cells. If not, it is recommended to include data for other (potentially higher) current densities.
2. Crossover is a significant concern in batteries, and in this thesis, it has been identified as the primary cause for capacity decay, which is highly plausible. Is there any direct evidence, such as characterizing the lithium side interface? Additionally, conducting a simple experiment to evaluate TEMPO crossover, such as using a two-compartment setup with one compartment containing pure PC and the other

containing TEMPO/PC, could provide valuable insights. Monitoring the pure PC compartment over time could yield useful information.

3. It would be helpful to understand how the ionic conductivities of the composite electrolyte were measured. Were any liquid electrolytes involved? If not, how does bare PVDF exhibit ionic conductivity, and what are the conductive ions involved?

Thank you for the opportunity to provide feedback, and I wish you all the best.

Provisional Recommendation

☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*

☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*