

SaFC: Consortium for Safe Battery Systems for Extreme Fast Charging
Precourt Institute for Energy, Stanford University

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1. Introduction

The energy storage market has seen a massive growth spanning the applications in electrical vehicles, stationary storage and consumer electronics. By 2030, the annual market for electrochemical energy storage will reach US \$1 trillion, exceeding that of the microelectronics industry today. Extreme fast charging, with a goal of 10-minutes recharge time or shorter, is poised to accelerate mass market adoption of electric vehicle, curb greenhouse gas emission and in turn, provide nations with greater energy security. For mobile electronics, the aggressive deployment of power-intensive 5G communication calls for fast charging of batteries several times per day.

However, the realization of such goal requires research and development across multiple levels, from charging infrastructure, vehicle and battery package designs and down to individual batteries. The battery cells and systems have been a key technical barrier. The state-of-the-art high-energy lithium-ion batteries with graphite anodes and transition metal oxide cathodes in liquid electrolytes are unable to achieve the fast charging goal without negatively effecting electrochemical performance and safety. The new high capacity anodes materials (Si, Li metal, S) and solid-state chemistries afford new opportunities as well as challenges for fast charging.

2. A Crosscutting Consortium

Stanford University is forming an academic-industrial Consortium for Safe Battery Systems for Extreme Fast Charging (SaFC) to meet the needs of the rapidly growing consumer electronics, electric vehicle and grid storage markets. The focus of SaFC is on the battery cells and systems and collaborates with Bits and Watts Initiative of Precourt Institute for Energy on charger and charging infrastructure.

The need for a consortium is rooted in the multidisciplines crossing multiple length scales required to tackle this grand challenge in the existing and emerging battery cell chemistries: **(1) Extreme fast charging in the existing battery cells with graphite anodes and lithium metal oxide cathodes (2) Extreme fast charging in emerging high energy chemistries (Si and Li metal anodes, Sulfur cathodes) and solid state batteries (3) Data-driven approach to design the protocols of extreme fast charging with excellent safety and battery life. (4) Sensing, thermal management and integration of battery cells into packs and systems.** The consortium will involve Stanford faculty members working across these areas and industry partners engaged across materials, cells, packs and systems.

3. People

Faculty, staff and students from Stanford's School of Engineering and School of Earth, Energy & Environment will work alongside industry partners and stakeholders.

Faculty

Zhenan Bao	Department of Chemical Engineering
Fu-Kuo Chang	Department of Aeronautics and Astronautics
William Chueh	Department of Materials Science & Engineering
Yi Cui	Department of Materials Science & Engineering
Christian Linder	Department of Civil and Environmental Engineering
Simona Onori	Department of Energy Resources Engineering
Evan Reed	Department of Materials Science & Engineering
Jian Qian	Department of Chemical Engineering

Staff:

Jimmy Chen	Precourt Institute for Energy
Tracy Turner	Precourt Institute for Energy

4. Research Pillars

Below, we briefly describe research pillars for the first three years of SaFC, along with the need for industrial input and participation.

A. Extreme fast charging in existing battery cell chemistries

Existing Li-ion batteries are dominated by graphite anodes and various lithium transition metal oxide cathodes (LCO, LFP, NMC, NCA) and will play a key role for next decade. The Li-ion battery cell technologies are conceived as a major technical barrier to fast charging. The current high-energy cells with graphite anode and metal oxide cathode in liquid electrolyte are unable to achieve the SaFC goal without adversely impacting battery performance and safety. When being charged at high rates, various polarizations (ohmic, concentration and electrochemical polarizations) inside the battery will result in limited utilization of active materials, increased propensity for Li plating, excessive heat generation, etc.

To effectively address these challenges, SaFC will study the main limitations of current battery materials towards <10 min fast charging from mass transport and charge transfer perspectives, and generate creative designs on the materials sizes and morphology, electrode structure. Battery cell thermal challenges under fast charging conditions are also considered with possible solutions proposed. Moreover, as increased charging rate will likely introduce new degradation mechanisms, advanced characterization techniques with X-ray and cryo electron microscopy will be used to deepen our fundamental understanding on the impacts of extreme fast charging and to inform more rational material designs. SaFC will also develop better safety strategies for fast charging than the current methods.

Industrial input & participation: SaFC to incorporate industry feedback on potential materials and electrode structure, appropriate cost structures, and performance metrics such as charging power and cycle life.

B. Extreme fast charging in emerging battery chemistry and solid-state batteries

There has been very exciting progress on the new high capacity electrode chemistries including Si and Li metal anodes and S cathodes. Particularly, Si is considered as a very promising anode to be deployed by industry. These new electrode chemistries have different voltage range from the existing Li-ion battery electrodes with respect to Li metal plating and liquid electrolyte oxidation and the lithium mass transport rates inside these materials and crossing the solid-electrolyte interphase are also different. In addition, the emerging solid-state electrolyte and batteries represent another very exciting direction. It is important to explore the opportunities of extreme fast charging in these emerging electrode chemistries and solid-state batteries.

SaFC will study and compare the new electrode chemistries with the existing Li-ion chemistries, generate the nanoscale materials and electrode design to enable the extreme fast charging for the new chemistries, and discover the liquid electrolyte specifically beneficial to the new chemistries. For solid-state batteries, particular attention will be paid to understand the chemomechanical issues of interfaces under the extreme fast charging condition. Similar to the existing Li-ion cells, battery cell thermal challenges under fast charging conditions will also be studied. Advanced characterization techniques with X-ray and cryo electron microscopy will be used. SaFC will also develop safety strategies to enable these new battery chemistries for fast charging.

Industrial input & participation: SaFC to incorporate industry feedback on comparing new materials with the existing materials, appropriate cost structures, and performance metrics such as charging power and cycle life.

C. Data-driven approach for extreme fast charging protocols

The existing batteries are usually evaluated under constant current charging followed by constant voltage holding. Some industries started to implement more complex charging protocols in consumer electronics and electrical vehicles in order to speed the charging rate yet maintaining the cycle life and safety with success. Here there are big opportunities to use data-driven approach to correlate a vast range of parameters (cycle life, safety, current, voltage, capacity, impedance, temperature, time, Li metal plating, etc.) to design the best battery fast charging protocol. Some of our preliminary research results indicate that this is a very fruitful direction to explore.

Industrial input & participation: SaFC will work with its partner to utilize the existing manufactured battery cells with good consistency to generate reliable learning data set.

D. System integration with sensing, control and thermal management

Beyond the battery cell level, the system integration is critical for realizing extreme fast charging. SaFC will conduct R&D in the following directions for system integration: 1) Implement various types of sensors including temperature, strain, electrochemical signal inside and outside the battery cells, and in the battery packs; 2) Develop battery management system integrated with battery packs with specific goals of extreme fast charging in mind; 3) Model the thermal profile and design thermal management systems to control the temperature of battery packs. 4) Develop the system-level methods to enhance the battery safety.

Industrial input & participation: Industries have a lot of experiences on system integration and will be able to provide inputs for collaboration.

5. Governance Structure

Consortium General Information & Membership

1. The consortium will consist of the core faculty, associated students and researchers, and StorageX industry members who commit to contribute one or more tokens per year to the consortium pool for 3 years. The industry members will be referred to as the consortium industry members.
2. Funds from the pool will be used to support one or more of the following: consortium seed projects, consortium research projects and associated researchers and students, consortium management, and consortium student internships

Industry Advisory Member

1. Only StorageX Sponsored members or Foundational members can become an Industry Advisory Member of a consortium.
2. Industry Advisory Members will make a three year commitment at a minimum of \$100k of affiliate funds/year to the consortium.

Governance

1. The **Consortium Executive Committee** will consist of the core faculty of the consortium and the Managing Director of the StorageX Initiative, and the **Industry Advisory Board** for the consortium will consist of the Industry Advisory Members of the consortium.
2. The Industry Advisory Board of the consortium will propose potential areas of research for the Consortium Executive Committee to consider.
3. The Consortium Executive Committee will create research proposals for the consortium affiliate funds, taking into account the input provided.
4. All consortium industry members are invited to provide input to the consortium research proposals.
5. The Consortium Executive Committee will make the final decision on consortium project funding, taking into consideration the input of the industry members.
6. The Consortium Executive Committee and the Industry Advisory Board members will meet twice/year during the StorageX research forum to address consortium business. The Industry Advisory Board members will also be invited to the monthly working meetings.
7. Management: Consortium administration, operations and management of the research are performed by the management team including the Consortium Executive Committee, and the Co-Directors and the Managing Director of the StorageX Initiative.