IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	**Energy Storage in Vanadium Redox Flow Batteries**	
Project Number	**IMURA1325**	
Monash Main Supervisor (Name, Email Id, Phone)	Dr. Tam Nguyen, tam.nguyen2@monash.edu, Phone: (61) 460-888-191	*Full name, Email*
Monash Co-supervisor(s) (Name, Email Id, Phone)		
Monash Head of Dept/Centre (Name,Email)	Prof. Phil Andrews, Head – School of Chemistry, phil.andrews@monash.edu,	*Full name, email*
Monash Department:	School of Chemistry, Faculty of Science	
Monash ADGR (Name,Email)	Prof. Peter Betts	*Full name, email*
IITB Main Supervisor (Name, Email Id, Phone)	Prof. Nagappan Ramaswamy, nagappan@iitb.ac.in, +91(22) 2576 7217	*Full name, Email*
IITB Co-supervisor(s) (Name, Email Id, Phone)		*Full name, Email*
IITB Head of Dept (Name, Email, Phone)	Prof. Mahesh Tirumkudulu, head.che@iitb.ac.in	*Full name, email*
IITB Department:	Chemical Engineering	

Research Clusters:

Highlight which of the Academy's CLUSTERS this project will address?
(Please nominate JUST ***one.*** *For more information, see www.iitbmonash.org)*

1	*Material Science/Engineering (including Nano, Metallurgy)*
2	*Energy, Green Chem, Chemistry, Catalysis, Reaction Eng*
3	*Math, CFD, Modelling, Manufacturing*
4	*CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control*
5	*Earth Sciences and Civil Engineering (Geo, Water, Climate)*
6	*Bio, Stem Cells, Bio Chem, Pharma, Food*
7	*Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng*
8	*HSS, Design, Management*

Research Themes:

Highlight which of the Academy's Theme(s) this project will address?
(Feel free to nominate more than one. For more information, see www.iitbmonash.org)

1	*Artificial Intelligence and Advanced Computational Modelling*
2	*Circular Economy*
3	*Clean Energy*
4	*Health Sciences*
5	*Smart Materials*
6	*Sustainable Societies*
7	*Infrastructure*

The research problem

The vanadium redox flow battery (VRFB) is regarded as one of the most promising candidates for future large-scale energy storage owing to its numerous advantages, including flexible and scalable energy capacity, long cycle life (up to 25 years), high safety and environmental friendliness (no fire risk), and the possibility of low-cost recycling of active materials. However, VRFBs still suffer from intrinsic limitations associated with the vanadium electrolyte, such as low solubility and poor thermal stability. In addition, parasitic reactions, particularly hydrogen evolution, can significantly deteriorate the overall battery performance. As a result, despite its attractive features, the unit cost of VRFB systems (USD /kWh) remains relatively high, which severely constrains their global market penetration (approximately USD 194 million in 2020).

Using aqueous electrolytes and carbon-based electrodes, a fundamental drawback of conventional vanadium redox chemistry is the relatively narrow electrochemical window, which is restricted by the onset of the hydrogen evolution reaction (HER) and the oxygen evolution reaction (OER). To enhance the kinetics of vanadium redox reactions, various surface modification strategies have been applied to graphite felt electrodes, including thermal oxidation, acid etching, and the introduction of electrocatalysts. While these treatments can improve vanadium redox activity, they may simultaneously accelerate HER and OER kinetics, an effect that has not yet been comprehensively investigated. In practice, such parasitic reactions not only consume a substantial fraction of the charging current but also generate gas bubbles within the porous electrodes, thereby reducing the effective surface area available for vanadium redox reactions. To date, no effective strategy has been successfully proposed and implemented in commercial VRFB systems to suppress parasitic HER and OER during operation.

The prospective doctoral candidate will review the status of VRFB to identify the problem statements and develop innovative solution for successful implementation of the technololgy.

Project aims

In this project, we aim to suppress parasitic side reactions occurring during the operation of VRFB electrolytes. The expertise and extensive knowledge of the IITB and Monash University supervisors in the fields of hydrogen evolution reaction (HER), oxygen evolution reaction (OER), and VRFB technology will be instrumental in developing advanced strategies to mitigate these reactions. The project is structured around three key objectives:

i) To develop a fundamental understanding of the kinetics of parasitic reactions in VRFB systems, including those occurring on both graphite felt electrodes and bipolar plates.

ii) To design and develop novel electrode modification strategies that effectively suppress parasitic HER and OER while maintaining or enhancing vanadium redox activity.

iii) To evaluate the impact of the newly developed electrodes on VRFB cell performance, with a particular focus on cycling stability, efficiency, and durability.

How skills/experience of the IITB and the Monash supervisor(s) support the proposed project

Prof. Nagappan Ramaswamy has extensive experience in the research and development of electrochemical energy storage and conversion devices such as fuel cells, electrolyzers and redox flow batteries. Specifically, he is experienced with electrocatalyst development, electrode design, membrane electrode assembly integration and stack design for various electrochemical devices. Prior to joining IITB in 2025, he was a Senior Research Engineer at General Motors (2014 to 2024) where he led two United States Department of Energy (DOE) projects focused on developing next generation electrode and membrane electrode assemblies for fuel cell electric vehicle applications (total project funding: ~7M US$). He has filed 15 issued or pending patents in the subject of electrochemical energy conversion and storage devices. Currently, at IITB he is involved with the establishing a state-of-the-art research facility in the fields of electrolyzers and redox flow batteries. His focus involves materials development, reactor design and diagnosis.

Dr Tam D. Nguyen is currently an ARC Early Career Industry Fellow at School of Chemistry, Monash University. He obtained his PhD degree in Materials Science from Nanyang Technological University (NTU), Singapore – ranked 12th best university in the world. Dr Nguyen has 4 years of productive postdoctoral experience at NTU (2018 - 2020) and Monash University (2021). He also has extensive industry experience when working as a Scientist by Energys Australia P/L from 02/2022 – 09/2024. Dr Nguyen's major research interests are in materials and technologies for renewable energy transformation and storage, including practical battery energy storage, green hydrogen production, and smart materials for energy conservation. His motivation in doing this research is to support the reliable and sustainable transition to renewable energy in Australia and worldwide to achieve a prosperous and safe future for humanity.
Dr Nguyen has strong experience in establishing and coordinating effective collaborations between academia and industry in various countries (Australia, Germany, UK, Singapore, Vietnam). He has a proven ability in translating fundamental research into applied technologies, design and construction of electrochemical device prototypes, and

development of commercial electrolytes, electrodes and combinations thereof. His notable achievements in this area include the invention of (i) a commercial electrolyte formulation for vanadium redox flow batteries manufactured by VFlowTech Pty Ltd; (ii) smart window prototypes designed and constructed for iGlass Asia Pacific Pte Ltd; (iii) methods of fabricating commercial zeoponic materials for Panasonic Asia Pacific Pty Ltd; (iv) scalable method for the fabrication of high-performance ultra-thin water electrolysis electrodes with Energys Australia Pty Ltd.

What is expected of the student when at IITB and when at Monash?

1. Fundamental investigation of the kinetics of parasitic reactions (IITB)

The kinetics of the hydrogen evolution reaction (HER) and oxygen evolution reaction (OER) in vanadium electrolyte formulations will be systematically investigated using electrochemical techniques, including cyclic voltammetry (CV), electrochemical impedance spectroscopy (EIS), and chronoamperometry/chronopotentiometry. Initial studies will be conducted on well-defined model electrodes (e.g., glassy carbon electrodes and carbon plates) prior to extending the investigation to porous electrodes such as graphite felt. To clearly distinguish HER and OER processes from vanadium redox reactions, operando gas detection will be employed using a flow-cell configuration, combined with online spectroscopic analysis. All measurements will be performed over a relevant operating temperature range of 50–60 °C to establish a comprehensive understanding of temperature-dependent effects on parasitic reaction kinetics under practical VRFB conditions.

2. Development of novel electrode modification strategies to suppress parasitic reactions (IITB and Monash University)

The central strategy for suppressing HER and OER is the development of selective surface modifications on porous graphite electrodes through catalyst decoration and/or conformal coatings. This project proposes the design of bifunctional catalytic systems that exhibit high activity toward vanadium redox reactions while being intrinsically unfavourable for HER and OER.

Among the most promising candidates for such selective catalysts is bismuth, which has been shown to significantly inhibit HER kinetics in aqueous electrolytes, while bismuth oxides have recently demonstrated the ability to suppress OER under acidic conditions. In addition, stabilising components based on antimony and lead will be explored to enhance catalyst durability—particularly at the positive electrode—and to further suppress both parasitic reactions. The effectiveness of the electrode modifications will be systematically evaluated by comparing HER and OER kinetics before and after surface treatment using standard electrochemical techniques, including cyclic voltammetry, electrochemical impedance spectroscopy, and chronopotentiometry.

3. Examine the effect of novel electrodes on the cell cycling performance (Monash University)
The extent of parasitic gas evolution will be quantitatively assessed through VRFB cell cycling tests integrated with in situ hydrogen and oxygen sensors, which will be designed and assembled at Monash University.

4. Develop electrochemical diagnostics to quantity VRFB parameters:
Design and develop electrochemical diagnostic protocols to be applied in VRFB cells to quantify various operating parameters such as crossover current, electrode degradation, side reactions etc.

Expected outcomes

The outcomes of these innovative studies will include:

(i) *Comprehensive understanding of the kinetics of the HER/OER involving under electrochemical process of vanadium electrolyte on the pristine and surface-modified porous graphite electrodes.*

(ii) *Effective approaches to completely eliminate the parasitic HER/OER in 20 cm^2 VRFB cell operated at a current density ≥ 100 mA cm^{-2} at different temperatures*

(iii) *Diagnostic tools to quantify the operational parameters of VRFB cells*

How will the project address the Goals of the above Themes?

Increasing energy demand coupled with the need to eliminate CO2 emissions have necessitated the exploration and implementation of alternative energy technologies such as wind and solar. This has become more critical in recent years as global warming reaches alarming levels due to further increases in CO2 emissions from fossil fuel consumption. However, the speedy development of renewables is currently creating challenges in the regulation of energy supply due to intermittency; this is creating demand for effective and stable energy storage systems. Integrating large-scale energy storage systems into the grid would improve the reliability, power quality, and economy of these renewable energy sources. The success of this project will enhance the performance, lowering the unit cost of VRFB and support the development and implementation of sustainable energy storage technologies.

How well the IITB and the Monash supervisor(s) know each other

We are new collaborators. We have had extensive email conversations and virtual one-on-one meetings to discuss about possible collaboration. We have found an alignment in the research topic that is of long-term interest and beneficial to both the institutes.

Potential RPCs from IITB and Monash

1. *Prof. Manoj Neergat, IITB, Department of Energy Science – he is an expert in electrochemistry and batteries.*
2. *Prof. Arindam Sarkar, IITB, Department of Chemical Engineering – he is an expert in electrochemistry & batteries.*
3. *Prof. Bharat Suthar, IITB, Department of Chemical Engineering – he is an expert in electrochemistry & batteries.*
4. *Prof. Alexandr Simonov, Monash University – expert in electrochemistry and electrolysis*

Capabilities and Degrees Required

1) *Preferred degrees – B.E or B.Tech or M.E. or M.Tech in one of the disciplines (Chemical engineering, Materials Science, Energy related engineering courses)*
2) *Preferred degrees – M.Sc (Chemistry or Energy related courses)*
3) *Capabilities (preferred) – background in electrochemistry, experimental experience in a laboratory and analytical characterizations.*
4) *Candidate should be highly motivated to perform independent research.*

Necessary Courses

1) *Electrochemical Reaction Engineering (Chemical Engineering)*
2) *Electrochemical methods*
3) *Energy storage and conversion*

Potential Collaborators

Not applicable

K**eywords** relating to this project to make it easier for the students to apply.

Renewable energy, Energy storage, Electrochemical Energy Conversion and Storage, Electrochemistry, Redox Flow Battery, Vanadium Battery