

Indian Science Technology and Engineering Facilities Map (I-STEM)

Invites application for

1. **Partial financial support for using R&D facilities in other institutions through the I-STEM web portal to Users from Academic Institutions and Start-ups (Format-1)**

Format for requesting support for accessing and using facilities through the I-STEM web portal.

(i) Details of the Personal Information

- a. Name of the Researcher/Faculty Member: Sayantanu Mandal
- b. Name of the Faculty Member: Prof. Kajari Kargupta
- c. Name of the Institution/Start-up: Jadavpur University, Kolkata, India
- d. Name of the Department: Department of chemical Engineering
- e. Degree registered for/Product being developed (for start-up): Ph.D.
- f. Mob. No.: (+91) 8670944128
- g. Email ID: sayantanum.chem.rs@jadavpuruniversity.in

(ii) Project/Research topic Details:

a. Project Title/Research Title: **Hydrogen energy production using sea water of Sundarban delta for remote power application.**

b. Sub area: Energy and Sustainable development

c. Area Description:

This area includes deploying renewable energy in India is to advance economic development, improve energy security, improve access to energy, and mitigate climate change. Sustainable development is possible by use of sustainable energy and by ensuring access to affordable, reliable, sustainable, and modern energy for citizens.

d. Aims & Objective (in Bullets):

The aims of this proposal are:

- ❖ Development of Solar Hydrogen based power generation using integrated seawater desalination(SWD)-continuous Hydrogen generation(CHG)-high-temperature proton exchange membrane fuel cell (HT-PEMFC) stack for remote applications especially in sea coast, mountain, battlefield, submarine where electric grids are not available.
- ❖ The Sea water from the locality of the Sundarban area of West Bengal will be collected, tested and economically desalinated utilizing solar energy. Interfacial Solar heating and recycling of vaporization enthalpy will be adopted to achieve low-cost high efficient desalination of seawater to produce high-quality water and it will be used for the continuous generation of green Hydrogen.
- ❖ Graphene-based low-cost novel bimetallic core-shell heterogeneous nano-alloy catalysts that offer synergistic effect due to orbital overlap would be used for Hydrogen generation from hydrolysis of Sodium Borohydride.
- ❖ Graphene-supported transition metal-based (having half-filled d orbital that offers d-pi interaction with graphene and thereby enhances the hybridization, electron density and transport) dual functional (both anode and cathode catalyst) heterojunction (Z-scheme) (already developed in the laboratory) will be used as photocatalyst for photocatalytic water splitting of desalinated water and water vapour. A continuous heterogeneous catalytic reactor will be designed, modelled and simulated using the kinetic rate expression derived from batch reactor data.

- ❖ Hydrogen generation will also be performed by the photocatalytic splitting of desalinated water vapour in continuous mode. The hybrid Hydrogen generation system will be integrated with a single HT-PEMFC and dual functional graphene-based dual functional ORR and HER electrocatalysts the integrated system will be tested for power generation.
- ❖ Finally, an integrated SWD-CHG-HT-PEMFC stack system will be used for power generation. The I-V characteristics, power versus current characteristics, durability and transient response will be experimentally tested and simulated using COMSOL Multiphysics 5.6.

The specific objectives are

- ❖ Low-cost high efficiency Solar desalination of seawater collected from Sundarban delta area of West Bengal, India.
- ❖ Synthesis, characterization of reduced graphene oxide supported bimetallic Nano-hybrids of different morphology and testing their performance for Hydrogen evolution reaction (HER) from sodium borohydride using desalinated seawater of different water quality using batch and continuous reactor.
- ❖ Design and development of continuous Hydrogen generation reactor based on heterogeneous catalytic reaction kinetics extracted from batch reactor data. Continuous generation of Hydrogen using hydrolysis of Sodium Borohydride using desalinated sea water and low-cost graphene-based bimetallic catalyst. Study on the effect of operating variables.
- ❖ Synthesis, characterization of reduced graphene oxide supported transition metal based Nano-hybrid photo-catalyst/photo-electro-catalyst and study of their activity, solar to Hydrogen ratio for photocatalytic water splitting. An attempt will be made to develop a low-cost transition metal-based photo-electro-catalyst for the splitting of direct seawater.
- ❖ Continuous solar Hydrogen generation using desalinated water and water vapour and graphene-based heterojunction and hybrid photocatalyst
- ❖ Integration of SWD-CHG-HT-PEMFC unit cell and SWD-CHG-HT-PEMFC stack and performance monitoring
- ❖ Testing of I-V characteristics, power versus current characteristics, durability and transient response of SWD-CHG-HT-PEMFC will be performed experimentally.
- ❖ Simulation of the performance and energy optimization using COMSOL Multiphysics 5.6.

e. Duration (MM/YYYY):3 years

f. Project Summary:

Most of the Sundarbans areas remained without power for up to a week. The crisis of electricity is one of the major problems of the coastal areas of West Bengal because of rapid developments and urbanizations. They still depend on traditional sources like wood and kerosene in lightening their houses. The generation of electricity using our system which will desalinate the saline water and converts it into electricity via Hydrogen can meet their small demand for electricity in those areas. Here we propose production of clean Hydrogen using renewable sources sea water and solar light and its conversion to electricity and power using fuel cell for remote areas where electric grid is not available. An **integrated device for sea water desalination(SWD)-continuous Hydrogen generation(CHG) and electricity generation using fuel cell (HT-PEMFC)** proposed here for production of purified water, clean Hydrogen and electricity. In Kolkata, the average level of air quality index is 2.5 PM jumped to 14 times in just 4 months. Bengal has the largest number of polluted cities in the country when the concentration of the toxic PM-10 pollutant is taken into consideration, according to a report prepared by the international environmental organisation Greenpeace. To minimise somehow this problem we dealt with Hydrogen generation which fully carbon emission-free process. Around one out of every five persons in rural India, who do not have access to clean drinking water, is from West Bengal. Out of this 411 lakh population around 19% or 78 lakh villagers are from West Bengal. West Bengal has the second-highest number of villagers who do not have access to safe drinking water in India. Our device is capable of the production of clean water as well in the production of Hydrogen generation for the production of electricity.

- ❖ Continuous Water purification of the sea water for Hydrogen generation as well as purified drinking water purpose
- ❖ Interfacial Solar heating and recycling of vaporization enthalpy will be adopted to achieve low cost high efficiency desalination of sea water.
- ❖ Development of novel easily renewable film type catalyst and parallel path based continuous reactor for continuous Hydrogen generation at higher rate.
- ❖ Novel sodium borohydride Bead formation as a Hydrogen storage fuel. Unique easily replaceable Catalyst coated vessels and plates for faster generation of Hydrogen generation.
- ❖ Use of Graphene based bimetallic catalyst for Hydrogen generation from Sodium Borohydride: utilization of synergistic characteristic to enhance rate of production and lowering the catalyst loading.
- ❖ Utilization of two alternative routes of Hydrogen generation and their hybridization (demand based).
- ❖ Enhanced rate of Photo-catalytic Hydrogen generation directly from desalinated water vapour
- ❖ Use of graphene based heterojunction/Z scheme combining anode and cathode catalyst together for enhanced Hydrogen generation.
- ❖ Development of Integrated sea water desalination (SWD)-continuous Hydrogen generation(CHG)-high temperature proton exchange membrane fuel cell (HT-PEMFC) stack for higher power generation, longer durability and faster response.
- ❖ Combined experimental and theoretical (COMSOL Multiphysics simulation) approach to predict the power generation characteristics, and optimize the performance and efficiency of the hybrid SWD-CHG-HT-PEMFC This would help one to scale up.

The aims of this proposal is solar Hydrogen based power generation using integrated sea water desalination (SWD)-continuous Hydrogen generation(CHG)-high temperature proton exchange membrane fuel cell (HT-PEMFC) stack for remote applications especially in sea coast, mountain, battle field, submarine where electric grids are not available. Sea water from the locality of Sundarban area of West Bengal will be collected, tested and economically desalinated utilizing solar energy. Interfacial Solar heating and recycling of vaporization enthalpy will be adopted to achieve low cost high efficiency desalination of sea water to produce high quality water and it will be used for the continuous generation of green Hydrogen. Graphene based low cost novel bimetallic core shell heterogeneous nano-alloy catalyst those offer synergistic effect due to orbital overlap would be used for Hydrogen generation from hydrolysis of Sodium Borohydride. Graphene supported transition metal based (having half-filled d orbital that offers d-pi interaction with graphene and there by enhances the hybridization, electron density and transport) dual functional (both anode and cathode catalyst) heterojunction (Z scheme) (already developed in laboratory) will be used as photo-electro-catalyst for photocatalytic/photoelectrocatalytic water splitting of desalinated water and water vapour. Continuous heterogeneous catalytic reactor will be designed, modelled and simulated using the kinetic rate expression derived from batch reactor data. Novel film type (catalyst ink deposited on parallel plates as a film of different thickness using dip coater) and parallel path continuous reactor (developed in the laboratory). Hydrogen generation will also be performed by photo-catalytic splitting of desalinated water vapour in continuous mode. The hybrid Hydrogen generation system will be integrated with a single HT-PEMFC that uses novel portable and durable gel paste electrolyte (already developed in the laboratory) and dual functional graphene based dual functional ORR and HER electrocatalysts; the integrates system will be tested for power generation. Finally, integrated SWD-CHG-HT-PEMFC stack system will be used for power generation. The I-V characteristics, power versus current characteristics, durability and transient response will be experimentally tested and simulated using COMSOL Multiphysics. Attempt will be made to improve the solar to Hydrogen and Hydrogen to electrical energy conversion.

- ❖ During last few decades, continuous depletion of fossil fuel as well as enormous environmental pollution have raised the importance of clean Hydrogen energy generation using renewable sources. Hydrogen Generation in global Market is expected to grow at high rate, since 2018 to 2023. The significance of the project lies in production of clean Hydrogen energy generation using renewable sources sea water and solar light and its conversion to electricity and power using fuel cell for remote applications especially in sea coast, mountain, battle field as well as in undersea submarine where electric grids are not available.
- ❖ Here we propose high efficiency low cost solar desalination for production of high quality pure water followed by Hydrogen generation. Generation of high quality pure water using efficient desalination is of great importance for wellbeing of human society.

- ❖ Two different methods of Hydrogen generation (hydrolysis of Borohydride for higher rate and direct water splitting at lower rate of production) proposed in this project, will enable one to implement the technology immediately using desalinated sea water low cost catalyst and Sodium Borohydride and provide opportunity to address the process bottlenecks of low rate of Hydrogen production using water splitting. The hybridization of these two method based on desirable power demand will enable the immediate implementation of the still evolving technology.
- ❖ Scientifically, the project is of significance in development of low cost transition metal (having half filled d orbital) and graphene based nano-hybrid catalyst/photo/electro catalyst for Hydrogen and power generation. The d-pi interaction of transition metal and graphene would play significant role in hybridization, enhance the electron density and transfer. Graphene based such bimetallic core shell type nano-alloy catalyst would offer synergistic effect due to orbital overlap and would enhance the performance.
- ❖ Finally, the experimental as well as simulation frame work based on COMSOL Multiphysics 5.6 would help in detailed performance analysis and energy optimization which is useful for further scale up of the technology.

g. Technical Details

- a. TRL: TRL –II, Very close to the experimental proof of concept
- b. Methodology

Steps	Research design: work element	Methodology
I	Collection of sea water from Sundarban and determination of the Quality of water.	Measurement of water quality parameters (TDS, pH, Electrical Conductivity and Salinity required for Hydrogen generation
II	Solar Desalination of Sea water	Design of high efficiency low cost multistage desalination unit based on vapour enthalpy recycling
		Single stage and multistage desalination of sea water using solar simulator (Newport LCS-100) for different time duration and ambient temperature of operation
		Measurement of TDS, pH, electrical conductivity and salinity of the desalinated water: Determination of water quality of desalinated water before and after desalination. Optimization of process parameters
III	Synthesis, characterization of rGO supported bi-metallic Nano-hybrids of different morphology and testing their performance for Hydrogen evolution reaction from NaBH ₄ using desalinated sea water of different water quality using batch reactor	Synthesis of rGO by modified Hummer's method and Bimetallic catalyst using Polyol method varying the ratio of constituents.
		Morphological characterization: SEM, TEM, HR-TEM, Raman Spectroscopy and EDAX
		Identification of groups, bonds: FTIR, XRD
		Pore size analysis: BET
		Electrochemical characterization using AUTOLAB Potentiostat by Metrohm.
IV	Continuous generation of Hydrogen using hydrolysis of Sodium Borohydride using desalinated sea water and low cost graphene	Conductivity measurement by EIS and Electrochemically active surface area (ECSA) measurement by cyclic voltammetry.
		Performance analysis of the catalyst for Hydrogen generation by Hydrolysis of NaBH ₄ using desalinated sea water using batch and continuous mode of reactor at different operating conditions, catalyst loading, temperatures including ambient temperature. Evaluation of catalyst activity, TOF.
		Kinetic study and derivation of rate expression using integral method of analysis by fitting the experimental data with modified Langmuir Hinshelwood type kinetics
IV	Continuous generation of Hydrogen using hydrolysis of Sodium Borohydride using desalinated sea water and low cost graphene	(i) Synthesis of Reduced graphene oxide by modified Hummer's method and Nano-hybrid materials and electrodes: Hydrothermal, in-situ deposition of film on glassy carbon electrode and spray pyrolysis method
		((a) Morphological characterization: SEM, TEM, HRTEM, Raman Spectroscopy, EDAX

	based bimetallic catalyst. Study on effect of operating variables	(b) Identification of groups, bonds: FTIR, XRD (c) Pore size analysis using BET (d) Electrochemical characterization using AUTOLAB Potentiostat by Metrohm. <ul style="list-style-type: none"> Conductivity measurement by EIS and Electrochemically active surface area (ECSA) measurement by cyclic voltammetry (e) Determination of band gap using UV-Vis and Tauc plot analysis. (f) XPS analysis
V	Continuous solar H ₂ generation using desalinated water graphene based heterojunction and hybrid photocatalyst.	Photocatalytic water splitting and photo-electrocatalytic water splitting using different operation conditions using desalinated water Determination of solar to Hydrogen generation ratio and apparent quantum efficiency.
VI	Integration of SWD-CHG-HT-PEMFC unit cell and SWD-CHG-HT-PEMFC stack and performance monitoring	Development of unit fuel cell (HT-PEMFC) using low cost graphene based bimetallic electro-catalyst having low Pt loading and total inorganic gel electrolyte (portable) [earlier developed in the laboratory] Integration of continuous Hydrogen generation and fuel cell system keeping provision of Hydrogen storage element Measurement of I-V characteristics, Power-Current characteristic, durability and transient response time Fitting the unit cell PEMFC data using COMSOL Multiphysics simulation and extension of fitted model to simulate fuel cell stack data. Design and development of fuel cell stack based on simulation results. Generation of experimental data of the fuel cell stack integrated with CHG unit.
VII	Energy optimization of the integrated device using COMSOL Multiphysics 5.6	Energy optimization will be performed considering different strategy of waste heat utilization (i) Using load current during pre-heat period of the PEMFC. (ii) Using Thermoelectric generator for waste heat to surplus voltage (power) generation

c. Design & development

- ❖ Collection of seawater from Sundarban and determination of the Quality of water.
- ❖ Solar Desalination of Seawater: Generation of purified water.
- ❖ Synthesis and characterization of reduced graphene oxide supported bimetallic Nano-hybrids of different morphology and testing their performance for Hydrogen evolution reaction (HER) from sodium borohydride using desalinated seawater of different water quality using batch reactor.
- ❖ Design and development of continuous Hydrogen generation reactor based on heterogeneous catalytic reaction kinetics extracted from batch reactor data. Continuous generation of Hydrogen using hydrolysis of Sodium Borohydride using desalinated sea water and low-cost graphene-based bimetallic catalyst. Study on the effect of operating variables.
- ❖ Synthesis, characterization of reduced graphene oxide supported transition metal based Nano-hybrid photo-catalyst and study of their activity, solar to Hydrogen ratio for photo water splitting.
- ❖ Integration of SWD-CHG-HT-PEMFC unit cell and SWD-CHG-HT-PEMFC stack and performance monitoring.
- ❖ Energy optimization of the integrated device using COMSOL Multiphysics.
- ❖ Summarization and Final report.

d. Facilities and Instrumentation required:

i. Characterization tools

Characterization	Institute to be performed
-------------------------	----------------------------------

Scanning electron microscopy (FE-SEM), high resolution Tunnelling electron microscopy (HRTEM), Energy Dispersive Spectroscopy (EDS), X-ray photoelectron Spectroscopy (XPS)	Indian association of Cultivation (IACS) (Kolkata)
Fourier-transform infrared spectroscopy (FTIR), X-Ray Diffraction (XRD), Brunauer-Emmett-Teller (BET), Raman Spectroscopy, NMR	CRNN, Calcutta University (Kolkata)
Full profile Water testing, Thermal Gravimetric analysis (TGA)	Jadavpur University (Kolkata)
Gas Chromatography (GC-FID)	BITS Mesra (Ranchi)

ii. Instrumentation

e. Consumables (Scientific materials)

Consumables	Justification
Platinum coated electrodes (0.5 mg/cm ²)	Electrodes for operating fuel cell
Peristaltic pump, Hydrogen flow controller	For controlling the water flow for the reactor inlet
Temperature sensor controller (PID), Pressure sensor controller	For monitoring Hydrogen temperature and pressure
Sodium alginate, Chitosan, carrageenan	Polysaccharides for MOF catalyst
Cadmium sulphide	Chemicals for photocatalyst
Sodium borohydride	Chemicals for Hydrogen generation

h. **Expected output and outcome**

- I. Complete technology (including data set, operating variables, production rate, extent of desalination) of solar desalination of sea water of Sundarban.
- II. Bi-metallic photo-catalyst for Hydrogen generation from sodium borohydride, reaction kinetics from batch data.
- III. Complete technology of continuous Hydrogen generation from the hydrolysis of Borohydrides.
- IV. Photo-catalyst for Hydrogen generation through Photocatalytic water splitting.
- V. Complete technology of Photo-catalytic and/or Photo-electro-catalytic Hydrogen generation.
- VI. Complete technology of Integrated SDW-CHG-HT-PEMFC and power generation data.
- VII. Published paper and International Conferences.
- VIII. Patents
- IX.

i. **Funding required from I-STEM (with justification):**

Details of Requirements & Mode of the Engagement: (Attach the quotation for the consumables)

(i) Short term Engagement:

a. Usage of testing/characterization facilities across the country (Characterization Mode)

i. Testing Charges-

ii. Consumable charges-

iii. Travel Cost (Boarding and Lodging, if any)-

b. Usage of fabrication and testing facilities across the country (Fabrication Mode)

i. Fabrication and testing Charges-

ii. Consumable charges (if any)-

iii. Travel Cost (Boarding and Lodging, if any)-

(ii) **Medium term Engagement:**

a. Execution of project in any one of the Host Institution (Project Mode)

Fabrication and testing Charges	50,000/-
Consumable charges	45,000/-
Travel Cost	5,000/-

- i. Fabrication and testing Charges- 50,000/-

Justification:

The testing charges includes characterization of nanoparticles [Scanning electron microscopy (FE-SEM), high resolution Tunnelling electron microscopy (HRTEM), Energy Dispersive Spectroscopy (EDS), X-ray photoelectron Spectroscopy (XPS), Fourier-transform infrared spectroscopy (FTIR), X-Ray Diffraction (XRD), Brunauer-Emmett-Teller (BET), Raman Spectroscopy, NMR, Thermal Gravimetric analysis (TGA), Gas Chromatography (GC-FID)] and full profile water testing. The fabrication includes a self-designed Reactor for continuous Hydrogen generation and a self-designed Reactor for Solar desalination.

- ii. Consumable charges (if any)-45,000/-

Justification

The consumables charges include some of the chemicals used in the Hydrogen generation catalyst (Sodium alginate, Chitosan, carrageenan, Cadmium sulphide etc.) and for the operation of the fuel cells (Platinum coated electrodes (0.5 mg/cm²). The others are the accessories for the operation of the whole devices.

- iii. Travel Cost (Boarding and Lodging, if any)-5,000/-

Justification

The travel cost includes the lodging and boarding for the testing purposes only

For the completion of the project the other fund is arranged by

- ❖ Chemicals (Consumables) funds can have obtained by the departmental funds of Department of chemical engineering, Jadavpur University, Kolkata (Departmental funds)
- ❖ International Conferences and seminar expenses can be reimbursed using Technical Education Quality Improvement Programme (TEQUIP-III).
- ❖ Some characterization at departmental central research facility (CRF).
- ❖ Self-financed

b. Execution of project in Multi Host Institutions (Project Mode)

- I. Fabrication and or testing Charges
- II. Consumable charges (if any)
- III. Travel Cost (Boarding and Lodging, if any)

(Round-trip to the Host Institution by 2nd class (Non-AC) railway via the nearest route)

Details of User's Bank Account:

(Please send a copy of the cancelled cheque/copy of the passbook carrying all the information needed)

Beneficiary Name (User's name): Sayantanu Mandal

PAN: CETPM6086D

Bank Account No.: 50200022072490

Name of the Branch: Bandhan Bank, Gora Bazar-742101

IFSC Code: BDBL0002004

Note: Proposed proposal must be executed within stipulated duration (max. 6 month) to avoid fund availability issues. Travel form will be provided by the I-STEM office. The users will submit the technical report, original invoice (duly signed by the Head of the Institution) raised by the Host Institution through I-STEM portal only along with a copy of the travel forms and original tickets through post to the Nodal Officer, I-STEM, Indian Institute of Science, Bangalore. A scan copy of all the documents may be sent in advance.



Gora Bazar
Gora Bazar - 742101
IFS Code : BDBL0002004

VALID FOR THREE MONTHS FROM THE DATE OF ISSUE

D	D	M	M	Y	Y	Y	Y

Pay

या धारक को Or Bearer

रुपये Rupees

अदा करें

₹

A/c No.

50200022072490

Payable at par at all branches
सभी शाखाओं में सममूल्यपर देय

SAYANTANU MANDAL

कृपया ऊपर हस्ताक्षर करें Please sign above

⑈000011⑈ 7427500051 002146⑈ 31