Blue Energy Generation System

Research Proposal Meeting

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Outline

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- **Problem Statement**
- **Literature Review**
- **Motivation**
- **Objective**
- **Work Done**
- **Research Design**
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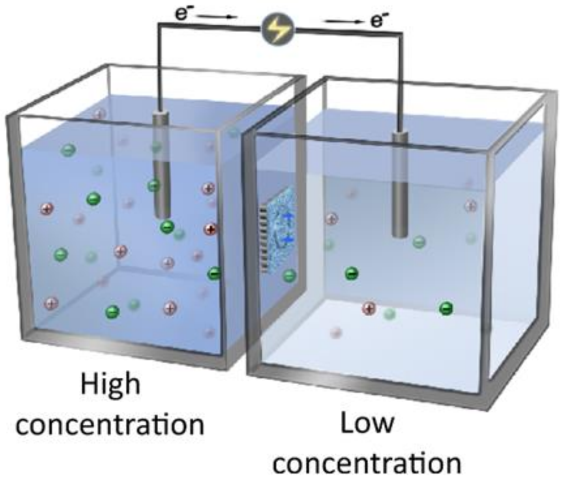
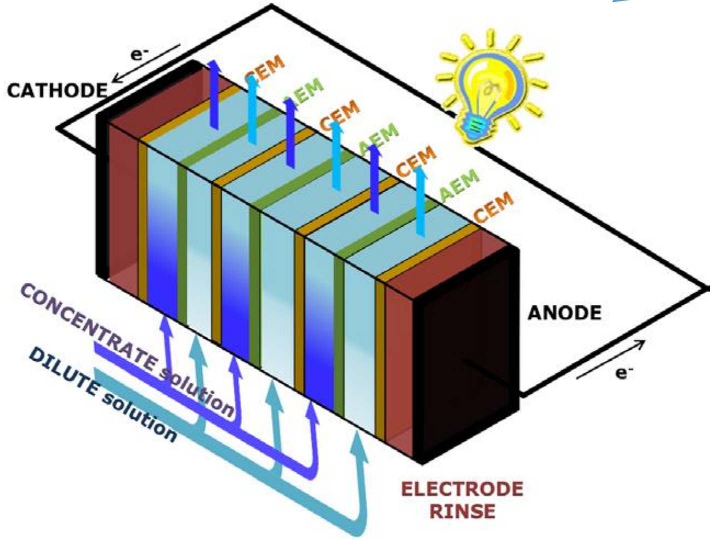
Introduction

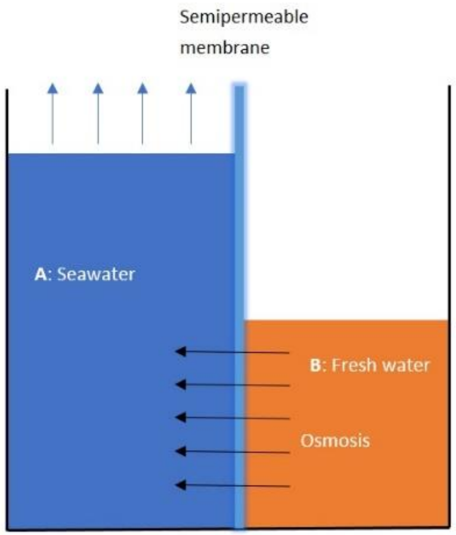
Blue Energy: Salinity gradient energy
(Membrane based technology)

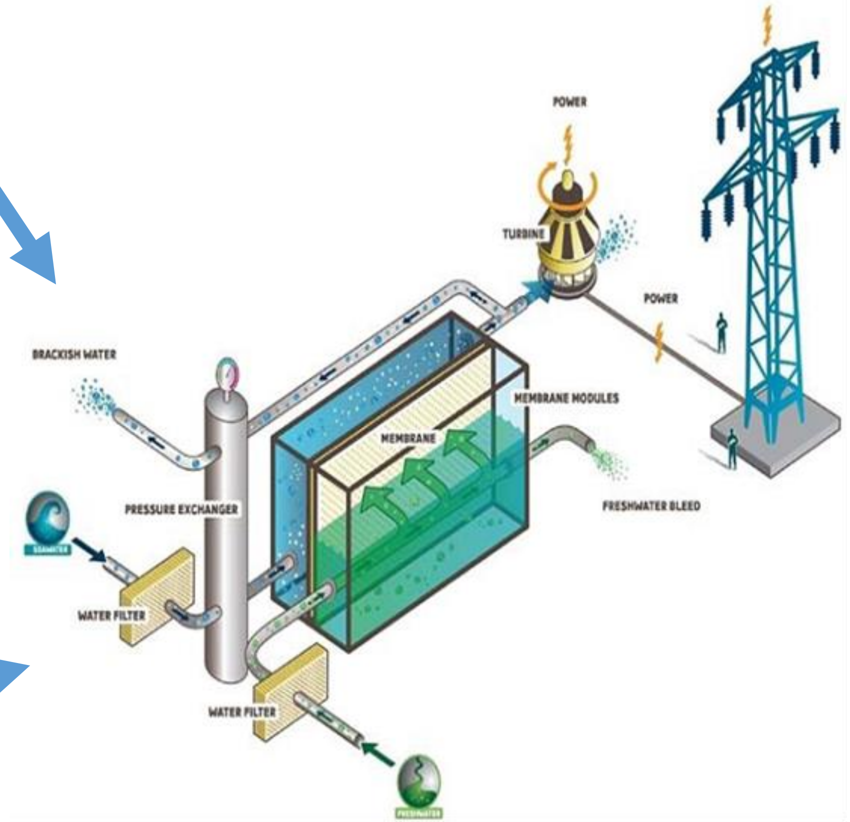




RED (reverse electrodialysis)
Ion selective membrane

Coelho, R.J.D. & Hilário, M.R. & Duarte, Duarte. (2014).





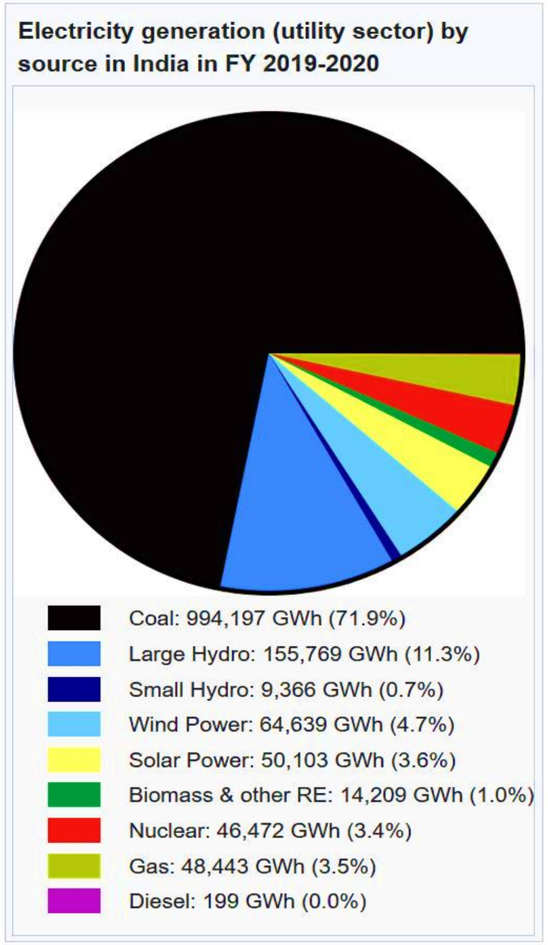
Pressure Retarded Osmosis (PRO)
Water selective membrane

https://www.ctc-n.org/technologies/osmotic-power

Problem Statement

- "World Energy Demand will be doubled by 2050".
- Current installed capacity = 370 GW (India)
- Fossil fuel domination causes environmental issue.

- Current Installed capacity = 85 GW (Renewable)
- Renewable energy (RE) aim = 175 GW (by 2022) = 500 GW (by 2030)
- Challenges with RE
  - Intermittency (Solution)
  - Geographical constraint
  - Compete with land use
  - Use of toxic material

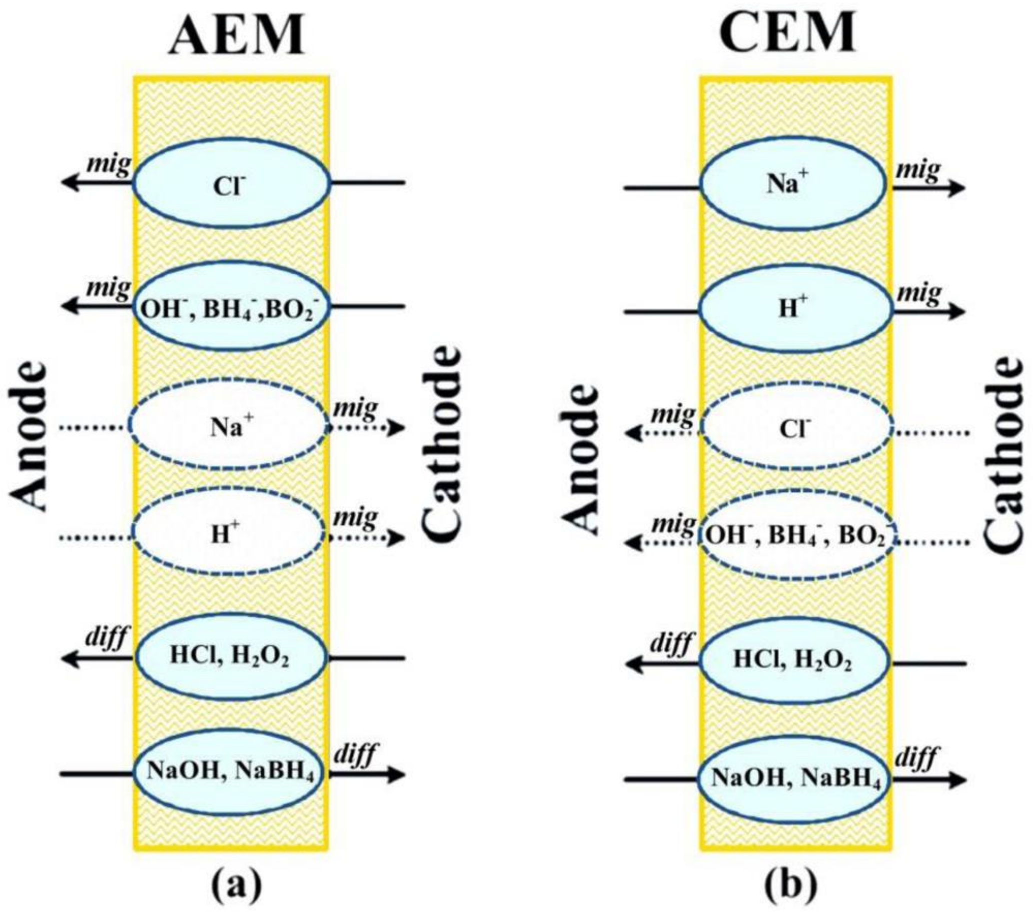


https://cea.nic.in/wp-content/uploads/annual_generation/2019/gen_target-2020.pdf

Literature Review

- Blue Energy - Membrane based technology
- Low efficiency- a few Watts per meter squared of membranes for sea/river combination (few $10 W/m^2$)[1,2]
- AEM - Anion exchange membrane
- CEM – Cation exchange membrane

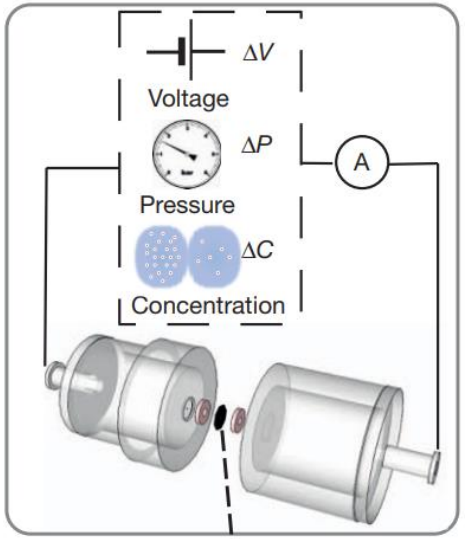
Ex: Nafion[1], Flemion, polycarbonate membrane[2] etc.



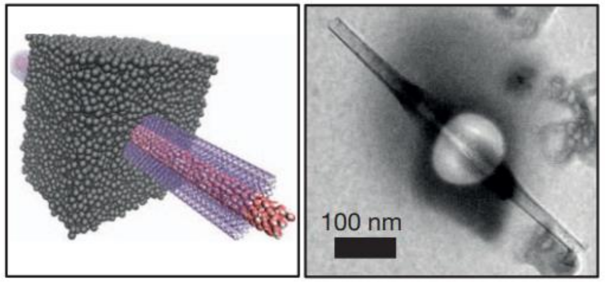
Šljukić et. al *Membranes* **2,** 478–492 (2012).

[1]. Avci, A. H. *et al.*. *Membranes* **10,** 168 (2020)
[2]. Kwon et. al Int. J. Energy Res. 2014, 38 (4), 530-537.

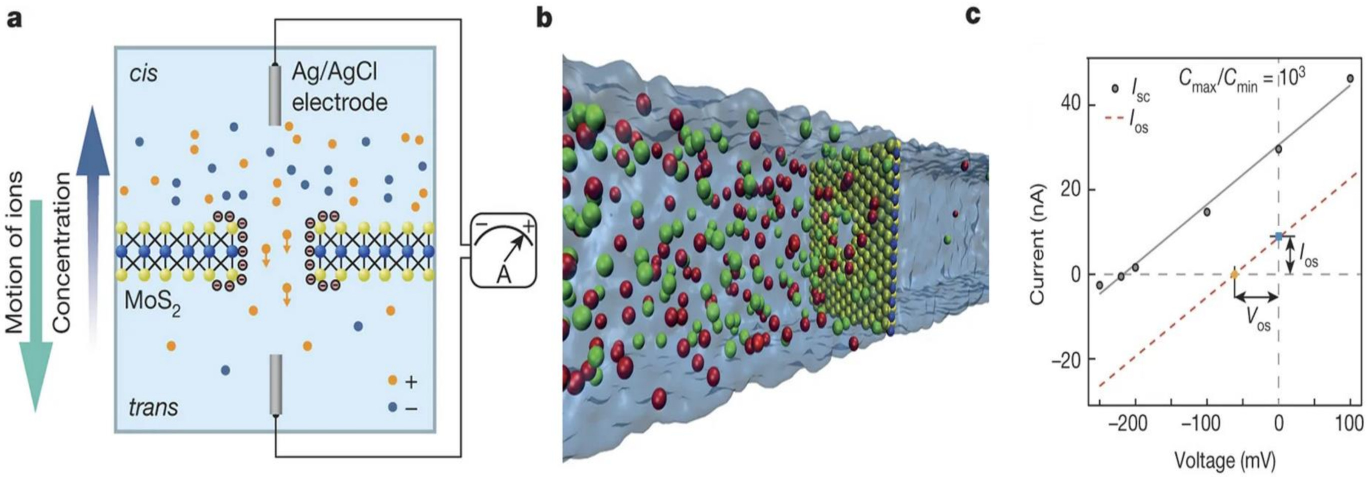
Literature Review



Transmembrane boron nitride nanotube



Improved efficiency (4kW/m²)



- Improved efficiency (1MW/m²)

Ultrathin, high surface charge density membrane – large power density

Siria, A., et al. & Bocquet, L. (2013) Nature,494(7438), 455–458.

FENG, J., GRAF, V.R NANDIGANA, K. ET AL. NATURE 536, 197–200 (2016).

Literature Review

Key Factor of Membrane

- Membrane Thickness
- Pore Diameter & Length
- Pore Geometry & Density
- Surface Charge Density

Desired property of Membrane

- High Conductance
- High Selectivity.
- Anti-fouling properties.
- Dimensional stability.
- High chemical stability and durability.
- Low cost.

Xiao et al., Ion Transport in Nanofluidic Devices for Energy Harvesting, Joule (2019)
Macha, Michal, et al. Nature Reviews Materials 4.9 (2019): 588-605.

Motivation

- Membrane Technology –

Conventional Membrane → (Nanomaterial With Nanopore) → New membrane → (Scaling up membrane) → Challenges with Scaling up

Conventional Membrane

1. Very Lowe Power density
2. Toxic Material
3. Poor Efficiency

New membrane

1. Very High Conductance
2. Extremely High Surface Charge Density
3. Higher Efficiency

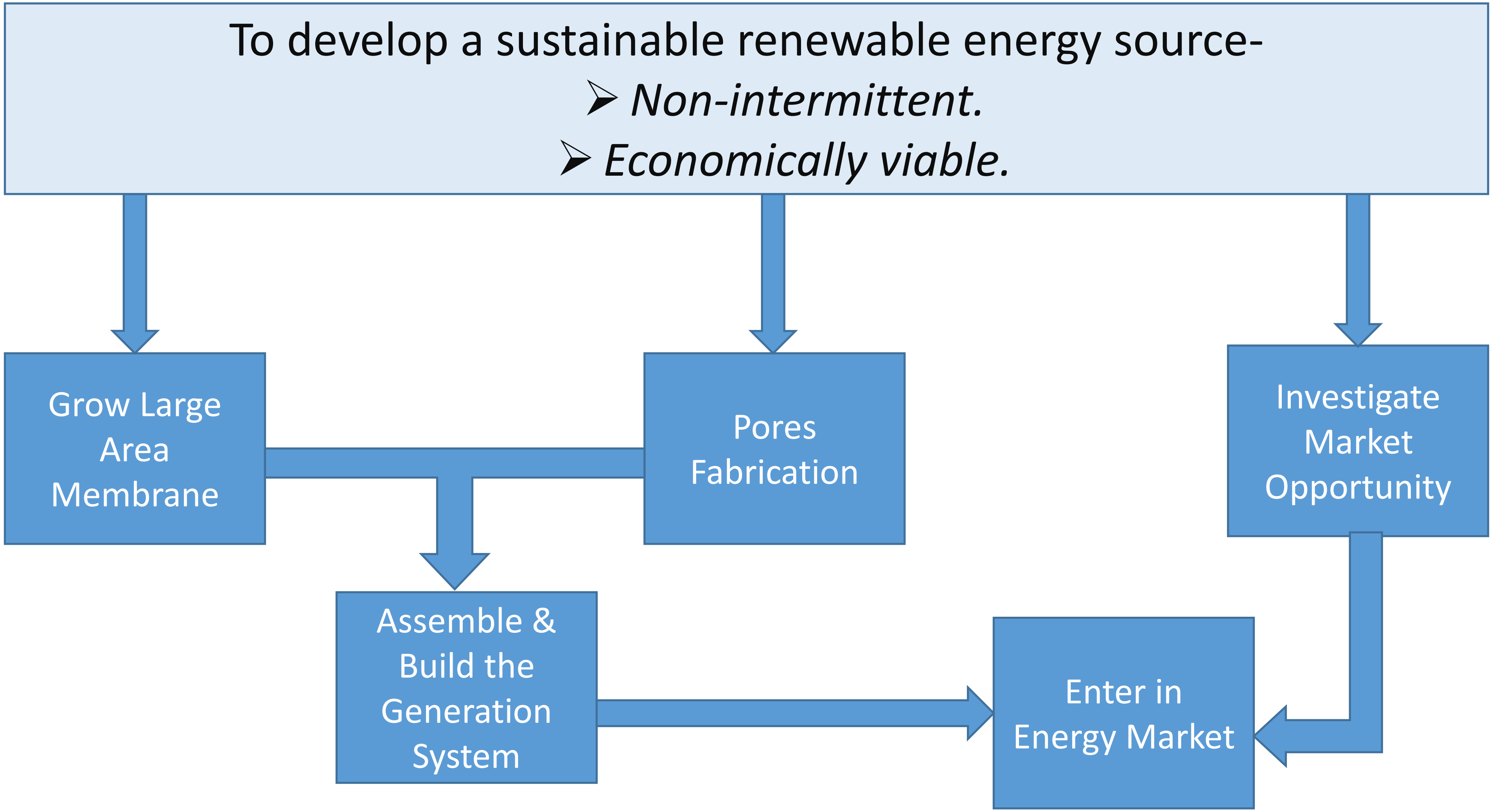
Challenges with Scaling up

1. Large area membrane fabrication
2. Slow & Complex pore fabrication
3. Clean Room Requirement
4. Various Expert Operators Required (TEM, Lithography, CVD,FIB etc.)
5. Environment Friendly Material
6. Economically Viable

- Market Challenges –

Renewable Policy/approval	Customer Segment	Customers Expectations	Uniqueness in product	Economically Viable

Objective


To develop a sustainable renewable energy source-
➢ Non-intermittent.
➢ Economically viable.
Grow Large Area Membrane
Pores Fabrication
Investigate Market Opportunity
Assemble & Build the Generation System
Enter in Energy Market

Work done

Key Partners	Key Activity	Value Proposition	Customer Relationships	Customer Segments
Investors Energy distribution companies Market	Electricity generation Electricity trade Market communication	Uninterrupted/Continuous power supply Renewable Transparency Trust Flexible tariffs	Energy services Help center	Group captive power producer Commercial users State electricity regulation companies Power Exchange
	Key Resources		**Channels**	
	Promotion policy, Raw materials, Human Resource, Grid, Investor.		MNRE, CERE/SERC, DISCOM, Grids, Open access	

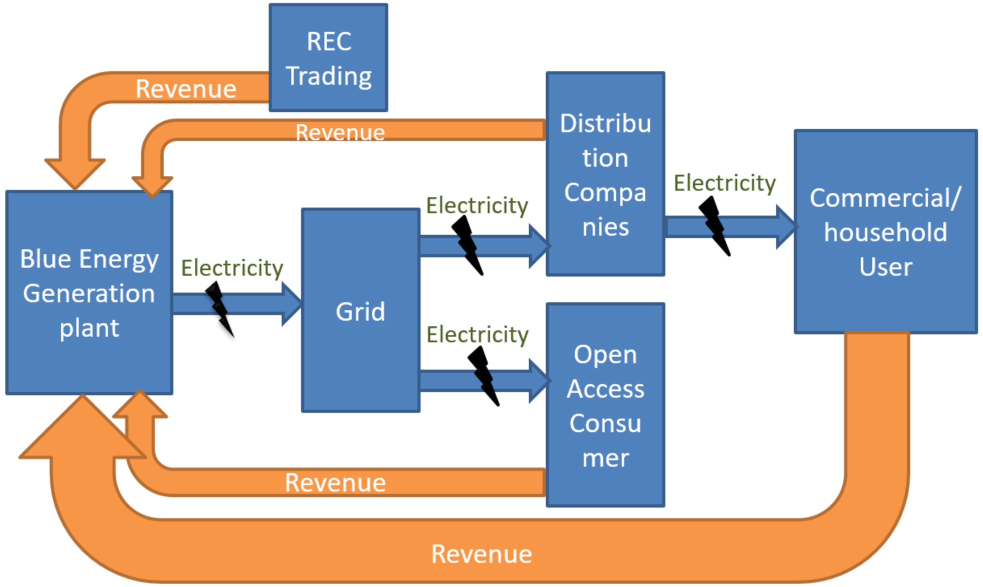
Cost Structure	Revenue Streams
Installation costs, Operational & Maintenance costs, Electricity trading costs, Grid usage fee, Costs for HR & personals, Office costs/facility costs.	Income through distributed electricity Income through REC trading

Business Model Canvas

(I-NCUBATE Cohort 7)

GDC innovation & Entrepreneurship at IIT Madras

- Develop and test idea from customer and market feedback for **the Blue FMA startup**.
- Customer discovery exercise.



Revenue model/Pricing

Work done

Key Finding from Customer meets

- RE-expansive than thermal
- Renewable Power-nonreliable

Key Learning

- Need to get RE tag from authorities
- Non intermittent
- Economically Competitive

Future Expansion Plan

- Need to get RE tag from authorities ✓
- Fund rising ✓
- Develop prototype ✓
- Scale to power plant ✓

Nandigana, "Blue Energy Scalable Renewable Energy Pilot Plant Industry", (IJSR), Volume 10 Issue 5, May 2021, 568 - 570

Growth of Two-dimensional $MoSe_2$

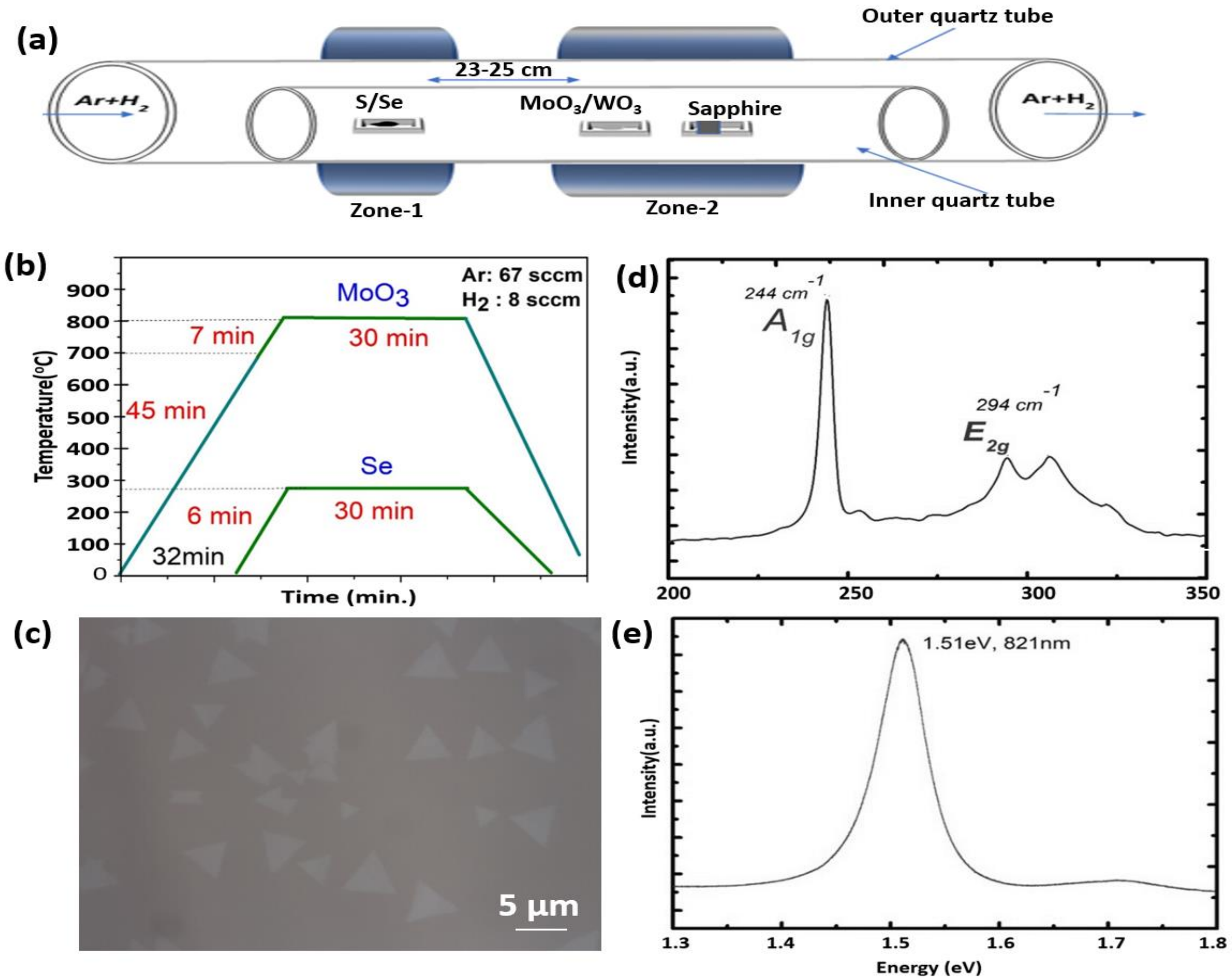
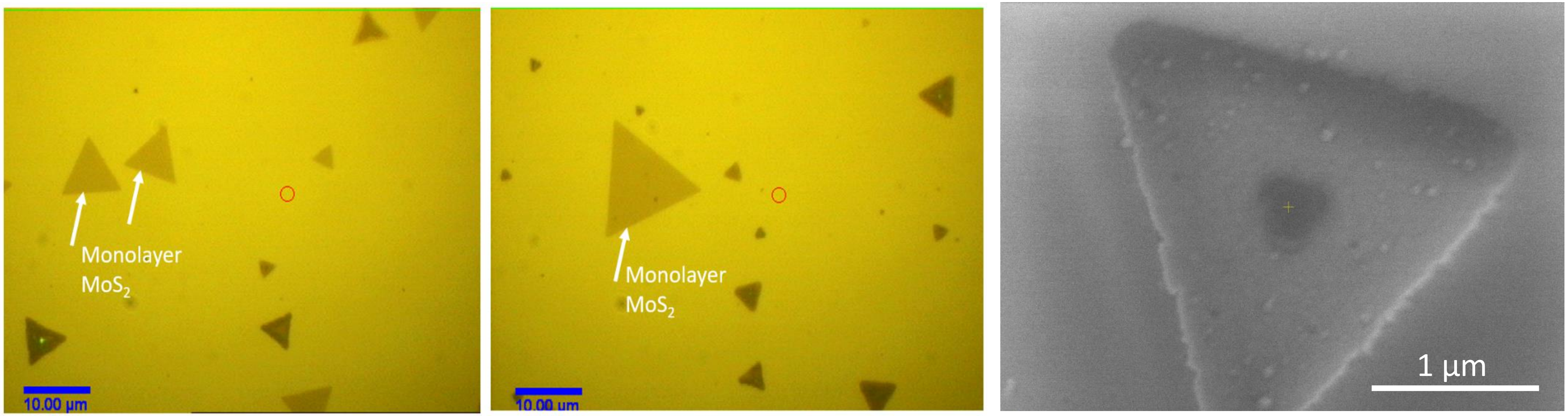


FIGURE. Growth process and characterization of monolayer MoSe2.

S. K. Yadav, V. Nandigana, and P. K. Nayak, AIP Conference Proceedings. Vol. 2265. No. 1. AIP Publishing LLC, 2020.

Monolayer MoS_2 using CVD and nanopore fabrication using FIB



(a) (b) (C)

Fig. (a,b) Monolayer MoS2 grown using CVD and, (c) nanopore fabrication using FIB

A Mathematical Framework that Matches Power Density of Nanoporous Membranes with Experimental Literature

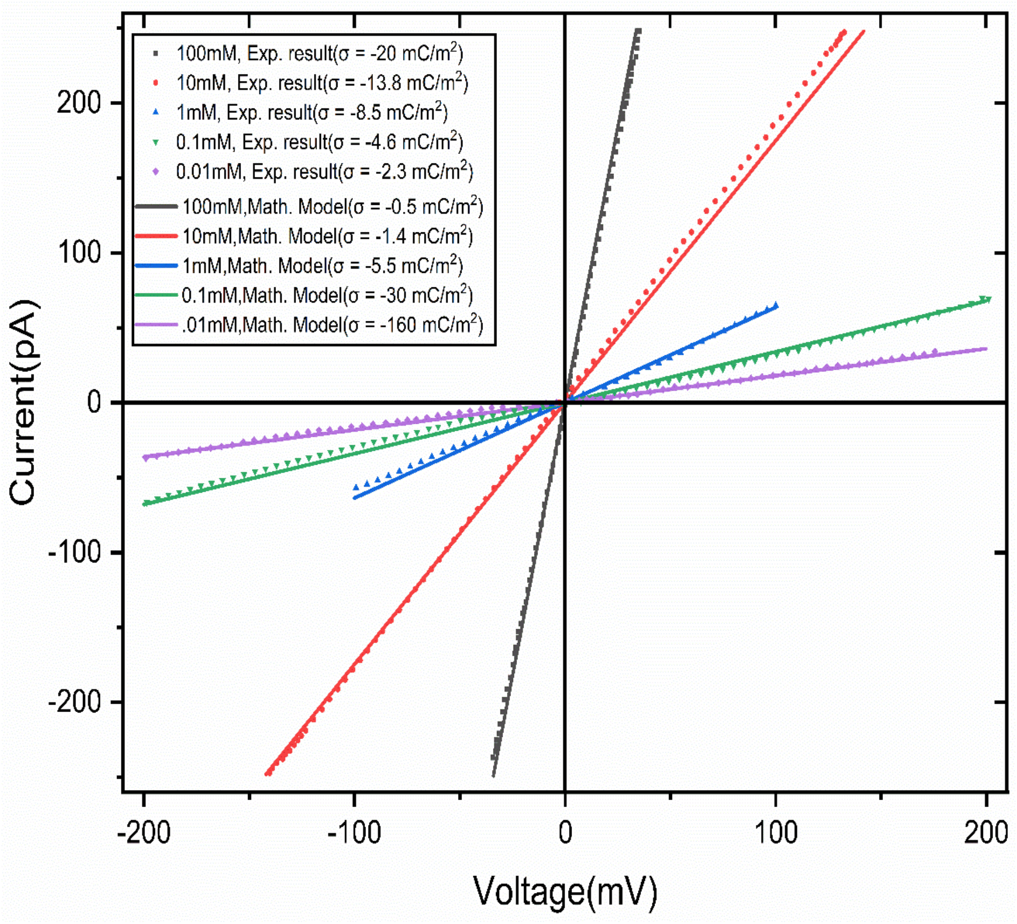


Figure: Comparison of I-V plots between Smeets et. al experimental data and our mathematical framework.

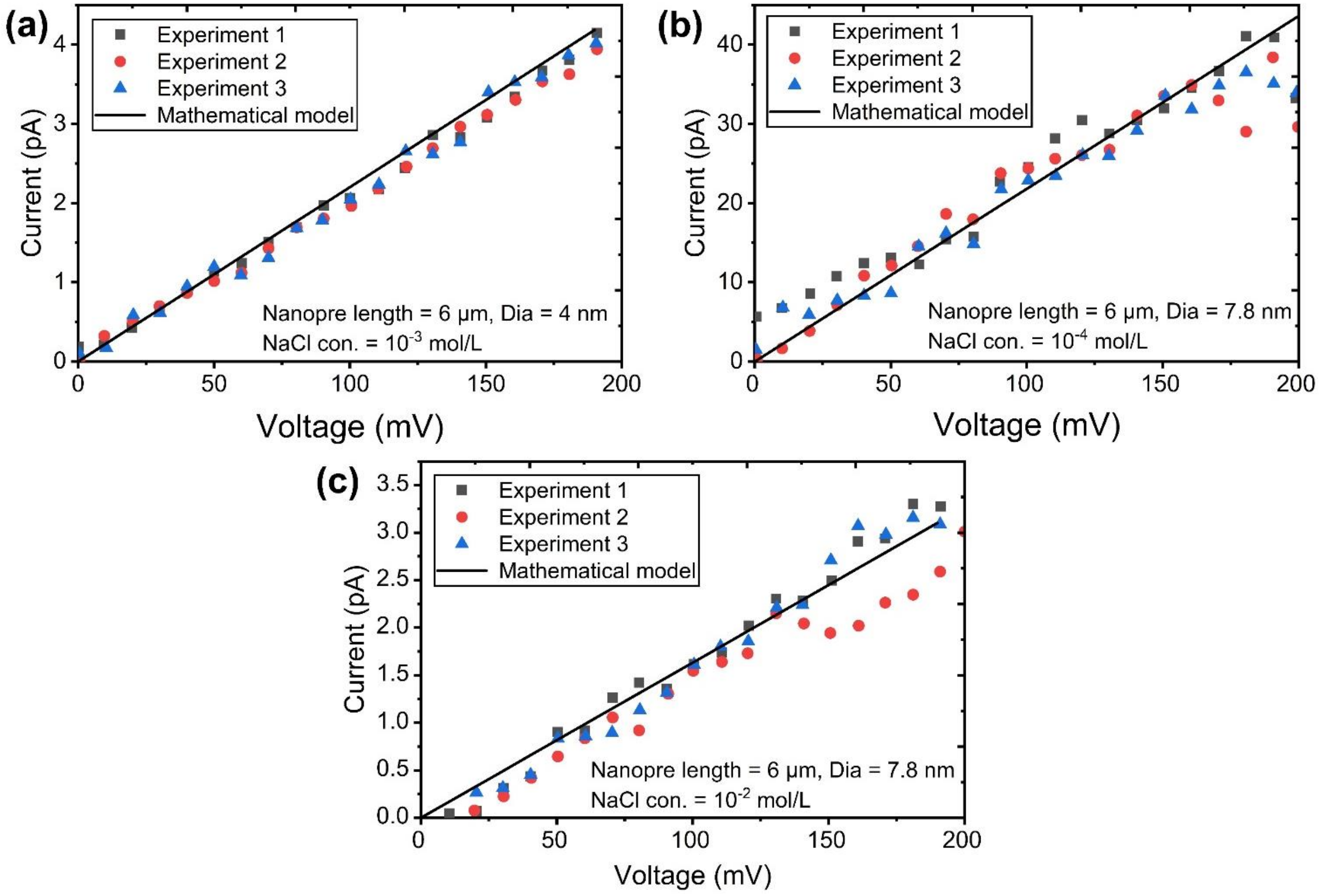


Figure (a-c): Comparison of I-V plots between Balme et al experimental data and our mathematical framework.

P. Avugaddi, S. Elangovan, S. K. Yadav, V. V. R. Nandigana International Journal of Science and Research (IJSR),Volume 10 Issue 5, May 2021, 486 – 491.

Research Design & Methods

- The pore conductance is not important tool in power density.
- The Power density not increase from nano to micro scale of pore diameter.

P. Avugaddi, S. Elangovan, S. K. Yadav, V. V. R. Nandigana International Journal of Science and Research (IJSR),Volume 10 Issue 5, May 2021, 486 – 491.

- Linear extrapolation of single nanopore performance to multiple pore is error-prone.
    - Ion concentration polarization effect arise in multiple nanopore membrane.
    - Ion selectivity reduces in multiple nanopore membrane.

- Preparing nanopore membrane for salinity gradient energy is not a viable.

Wang, Li, et al. "Nanopore-Based Power Generation from Salinity Gradient: Why It Is Not Viable." *ACS nano* 15.3 (2021): 4093-4107.

Research Design & Methods

Experimentally –

↓

The mm size (1 mm and 2mm) single and multiple pore offering higher power density. (As we maintain the salinity gradient)

↓

The larger pore (cm size) allowing rapid mixing - hence maintaining salinity gradient across the membrane is not easy.

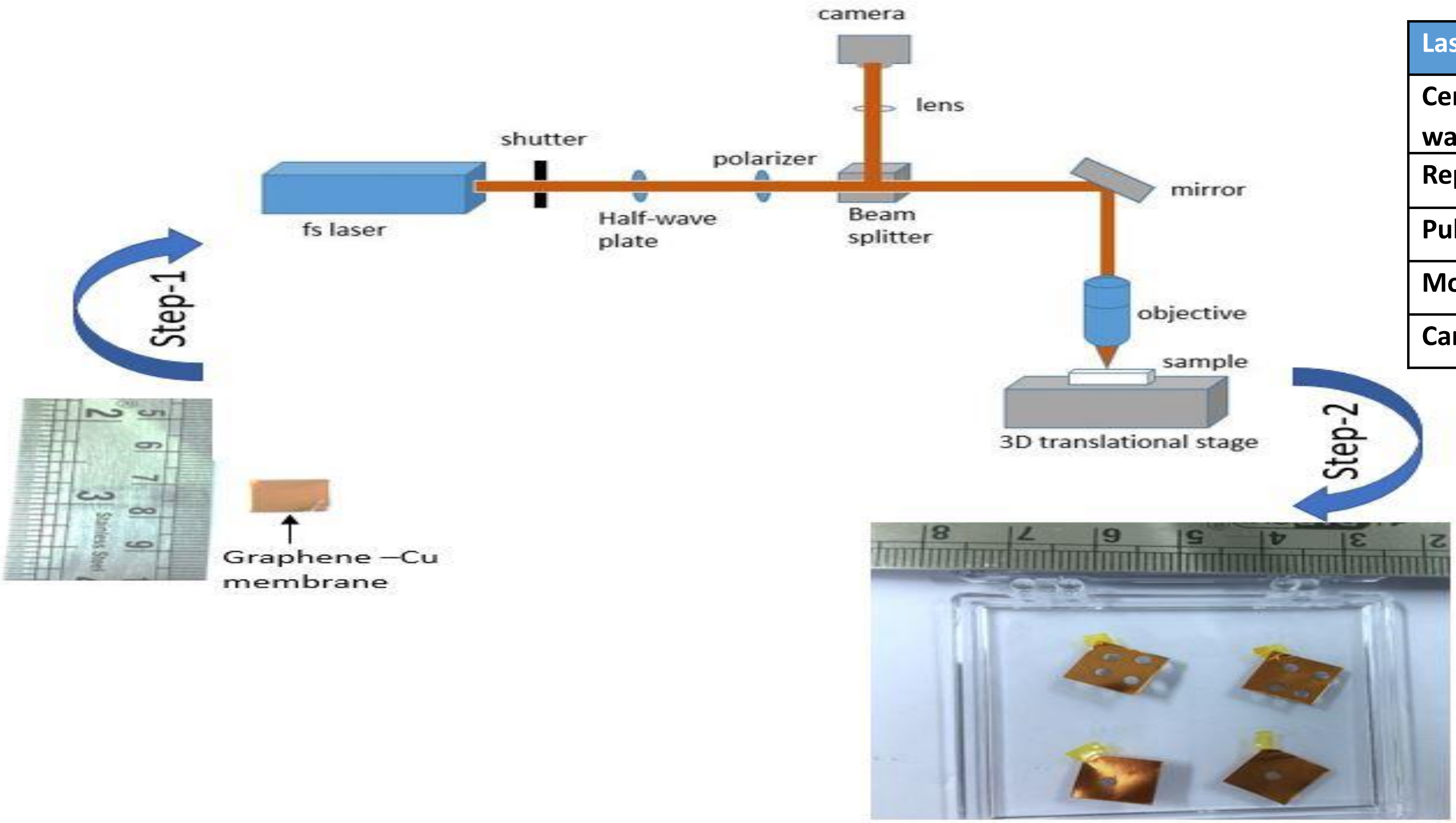
↓

we started with the mm size pore.

Research Design & Methods

	Component/Equipment	Specification
1.	Graphene-Cu Membrane	Monolayer graphene on 18 µm thin Cu (10 mm x 10 mm) from Graphenea
2.	Silicone Rubber	Thickness – 2mm, inner diameter- x mm, outer diameter – y mm
3.	Diffusion Cell	Borosilicate material (Design Customized)
4.	Peristaltic Pump	P120LS - Flow rate range (100 ml – 5 lit/min) ,Speed (20 – 196 RPM) by Ravel Hiteks P120S - Flow rate range (2 ml – 480 ml/min) ,Speed (10 – 196 RPM) by Ravel Hiteks
5.	Chemical Pump	Flow rate range (100 lit/min) by KEMP
6.	Pump Automation System	Control unit with GUI enabled system
7.	Source Measurement Unit (SMU)	2460 High current source meter, (Max. Current: 7A, Resolution: pA) (Max. Current: 100V, Resolution: µA) by Tektronix, Inc.
8.	Solvent Reservoir	HDPE (high density polyethylene material)
9.	Electrode	Pt and Ag/AgCl electrode
10.	Control Unit (CPU, Monitor)	Dell CPU (intel i7 processor, 32GB RAM, Window 10 OS) and Dell Monitor

Research Design & Methods



Laser system	Ti- Sapphire femtosecond laser
Central wavelength	800 nm
Repetition rate	1 kHz
Pulse width	< 35 fs
Motion controller	Newport XPS-RL
Camera	IDS camera manager

Figure. Fabrication of mm size pore on graphene-cu membrane.

Steps to house the membrane

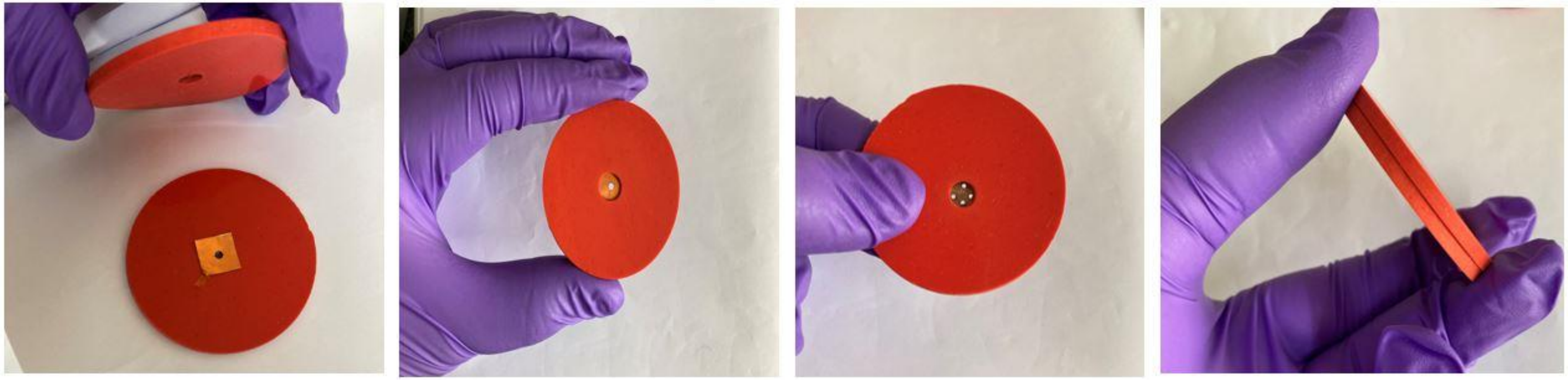


Figure. Sandwiching graphene-cu membrane between silicone rubber rings.

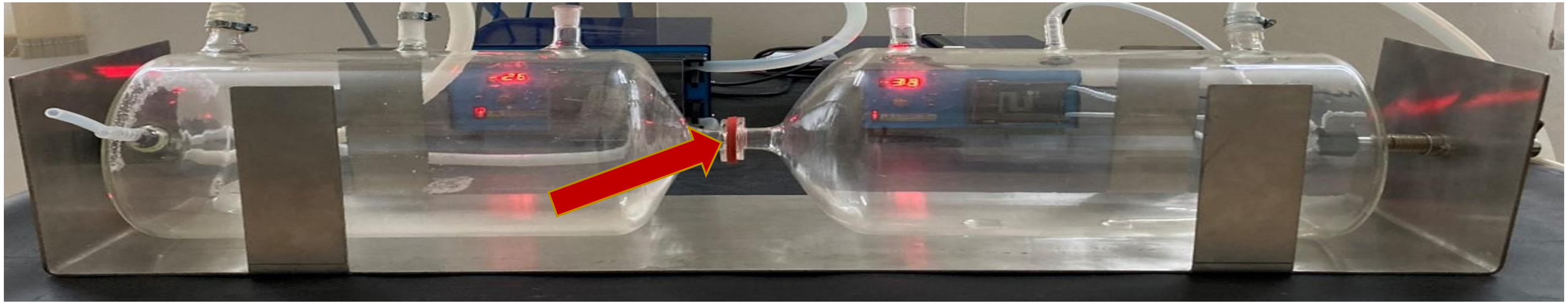


Figure. placing silicone rubber (housing the graphene-cu membrane) in diffusion cell set-up.

The diffusion cell

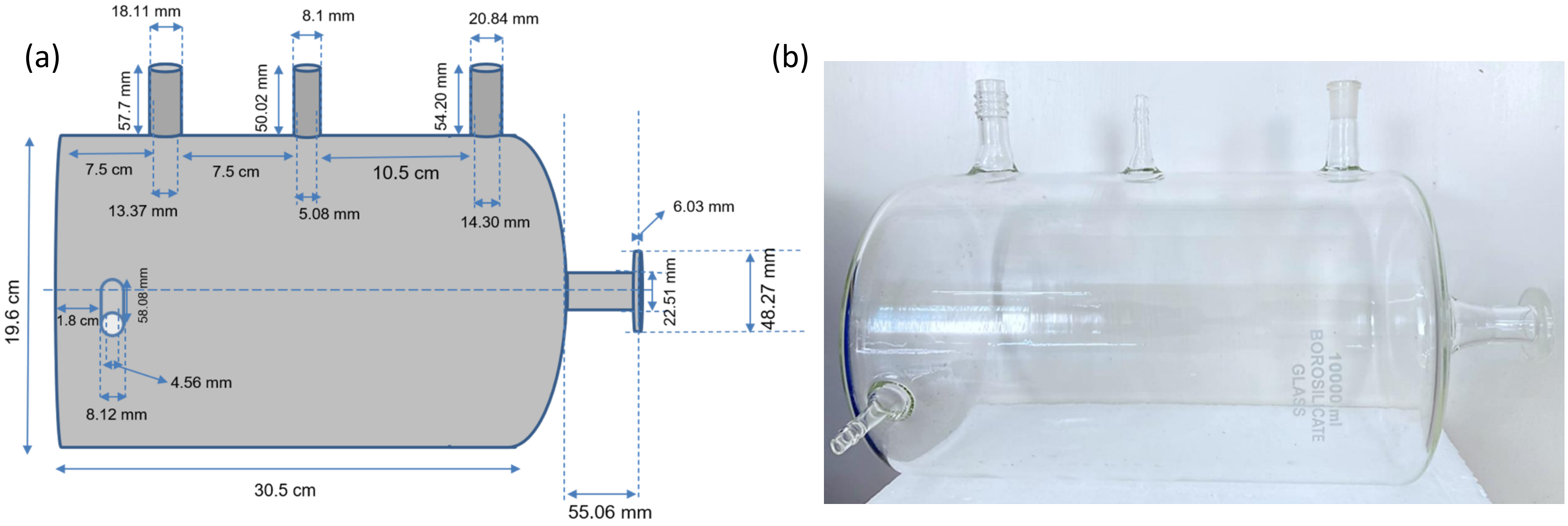
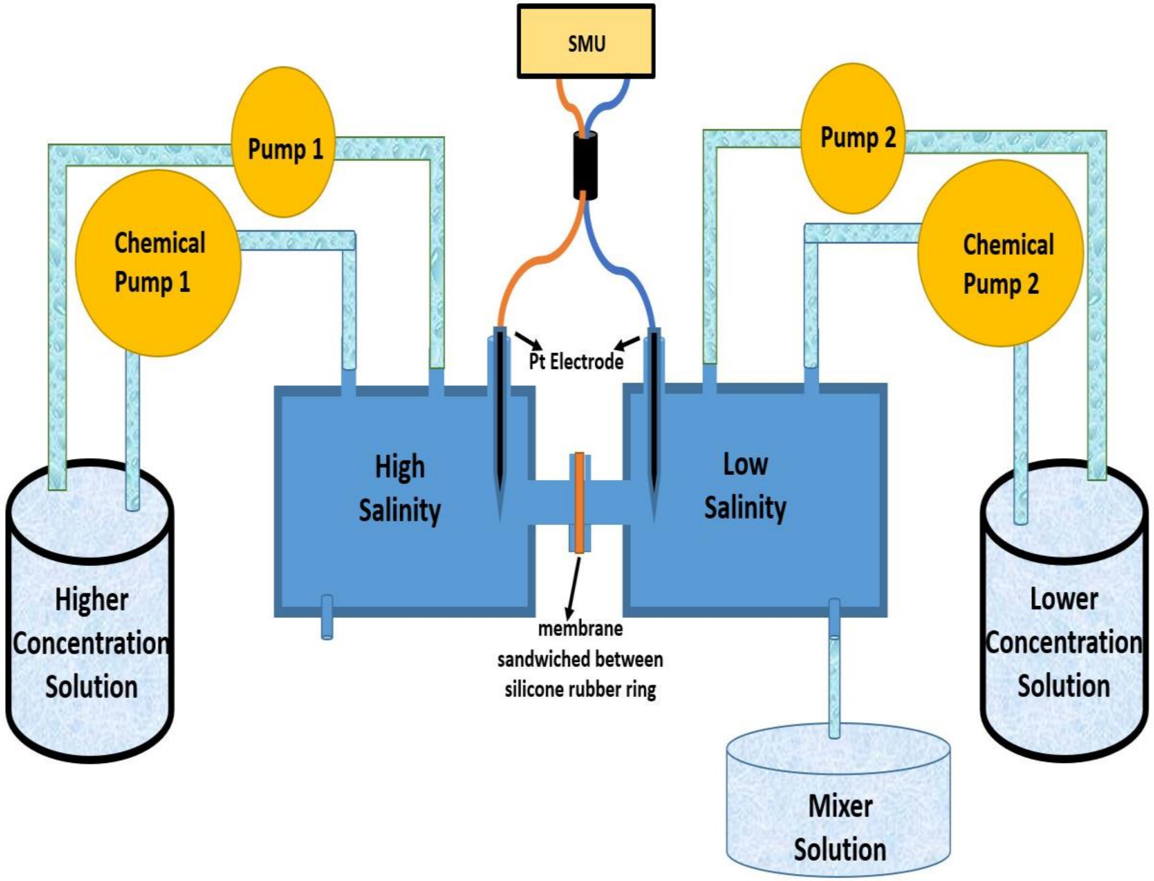


Figure . (a) Diffusion cell schematic with dimensions and (b) diffusion cell

First prototype setup



(a)

(b)

Figure . (a) The Schematic of blue energy generator and (b) the blue energy set-up image.

Next To Do

- The effect of -
  - mm-size pore 2D membrane in blue energy generation.
  - Salinity gradient variation on energy generation.
  - Surface charge density (by varying the pH of solution) on energy generation.
  - Pore size and pore density on energy generation.
- Identifying the way to scale-up the technology further to generate higher energy.
- Growing large area monolayer 2-D membranes.
- Fabricating different size and numbers of pores.
- Making the technology economically viable.

Published work/Awards/Patents

Publications

- S. K. Yadav, V. V. R. Nandigana, P. K. Nayak, Sequential growth of two-dimensional $MoSe_2$ - WSe_2 lateral heterojunctions, AIP Conference Proceedings 2265, 030699 (2020)
- P. Avugaddi, S. Elangovan, S. K. Yadav, V. V. R. Nandigana, "A Mathematical Framework that Matches Power Density of Nanoporous Membranes with Experimental Literature", International Journal of Science and Research (IJSR),Volume 10 Issue 5, May 2021, 486 – 491.

Patent

- V. V. R. Nandigana, P. K. Nayak, S. Krishnan, S. K. Yadav, A. Gopalakrishnan, Osmotic power generation system, World Patent, 2021.

Award

- NanoSparX award 2020 at Bangaluru India Nano (Venue-The Lalit Ashok Bangaluru)

Thank You.