

2025 SIDS NDE Joint Programme

Forum and Capacity Building
on Co-creation for System Transformation

PRESENTER

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Dr. Hanki Kim – Korea Institute of Energy Research, South Korea



OCEAN ENERGY PROJECT FOCUSING ON
SALINITY GRADIENT ENERGY
AND
ELECTROCHEMICAL OCEAN ENERGY CONVERSION

Introduction

CTCN TA: Country-wide Feasibility Study on the Potential of Ocean Technology Energy Conversion (OTEC), Guinea

Request Title: Pre-feasibility study on Salinity Gradient Energy Technology

Climate Objective: Mitigation of Climate Change

Sector: Energy

Link to CTCN Programme of Work: Energy Systems

Main results expected from TA:

- a) Increase capacity on non-GHG action-based Targets (under the PNG's NDC – increase data availability);
- b) Enhance data collection on OTEC potential in PNG;
- c) Increase penetration of OTEC in the country's energy mix;
- d) Develop National Policy on OTEC in PNG;
- e) Training and Capacity Building on OTEC in PNG.



Progress – Energy Sector in PNG

- ❑ Joint Collaboration between the Climate Change & Development Authority (CCDA), and the National Energy Authority (NEA) of Papua New Guinea.
- ❑ Technical assistance from CTCN and Korea.
- ❑ PNG Energy Targets:
 - NDC (Conditional), increase the share of renewables in the energy mix for on-grid connection by increasing installed renewable energy capacity from 30% in 2015 to 78% in 2030.
 - Government's National Electricity Roll Out Plan (NEROP), ensuring 70% access to electricity by 2030 (currently < 20% of households have access to electricity).
 - Vision 2050 (Overarching policy framework), Strategic Development Plan 2010 – 2030, Medium-Term Development Plan (MTDP)
 - Sub-sector Renewable Energy Policies – Bioenergy Policy, Geothermal Energy Policy, Hydro Energy Policy, Solar Energy Policy and Wind Energy Policy (all policies launch in 2025)



Progress - TA

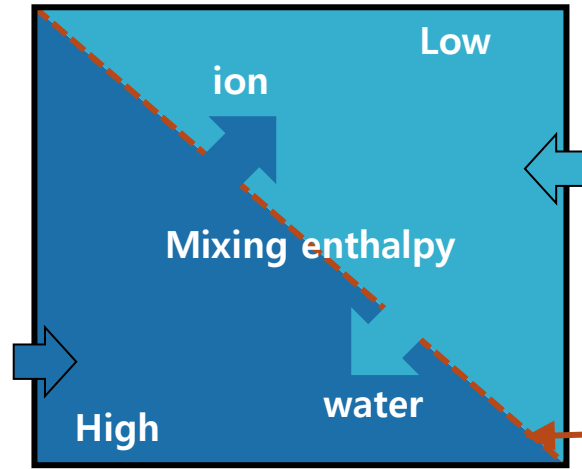
- ❑ Initial Inception Workshop was held in November 11 - 13, 2024. Representative from Korea Institute of Energy Research (KIER) and CTCN met with the PNG team – consisting of the NDE, NEA, NISIT, UPNG, PNG UoT, CEPA and others.
- ❑ Initial site visit to Lae, Morobe Province to examine the potential for the project in Markarm and Busu River and meeting with PNG UNITECH, 12 November 2024.
- ❑ Establishment of the Project Steering Committee (PSC).
- ❑ Second visit to PNG by KIER Team on 25 – 30th May 2025. Key objective of the second visit was to collect data samples and to install the prototype salinity gradient RED energy system equipment and to demonstrate its energy potential.
- ❑ Site visit to Kalo Village, in Rigo District of Central Province to collect sample data for testing and assessing the viability of the technology in PNG (collect data for pre-feasibility assessment).



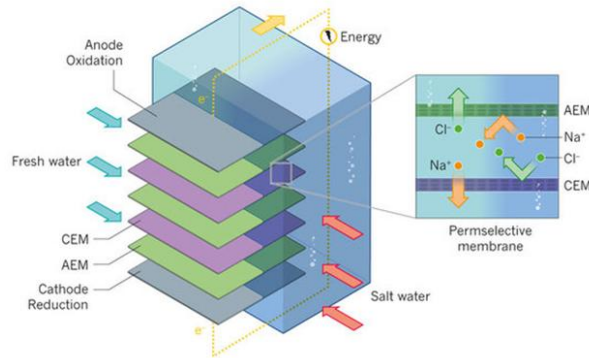




Principle: Salinity Gradient Power

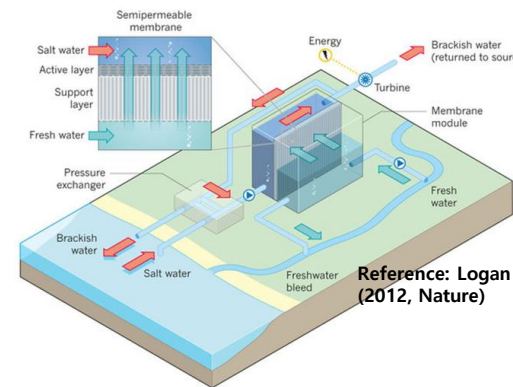


Reverse
electrodialysis, **RED**  Ion transport



Electrochemical technology

Pressure retarded
osmosis, **PRO**  Water transport
(osmosis)



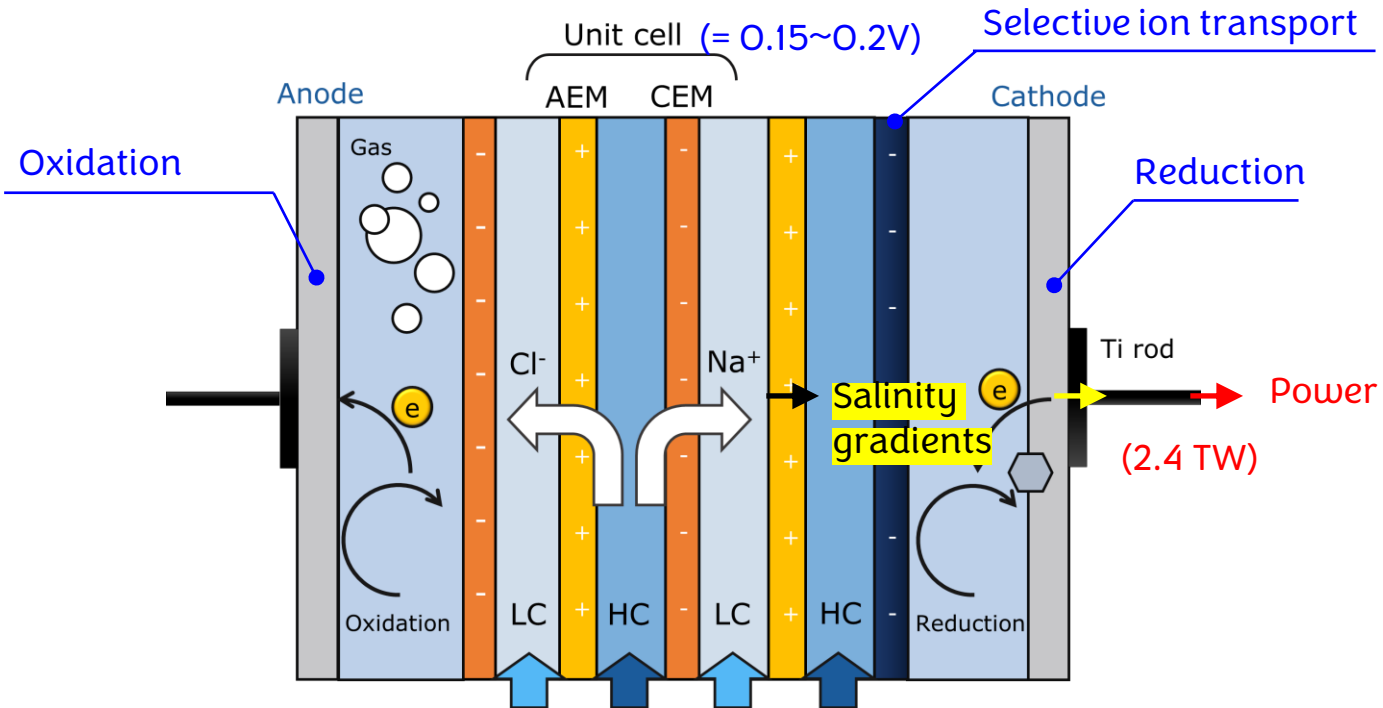
Reference: Logan and Elimelech
(2012, Nature)

Mechanical technology



Principle: Reverse Electrodialysis (RED)

❖ Schematic diagram of Reverse Electrodialysis (RED)



- Power generation by electrochemical reaction (like a fuel cell)
- Major components: (Stack) ion-exchange membranes and electrodes, (System) Pumps
- Chemical potential: 2.7 MJ/mol NaCl (equal to 200 m height of a Dam)
- Power density: $> 200 \text{ W/m}^2$ of electrode (or $0.5 \sim 1.0 \text{ W/m}^2$ of membrane)

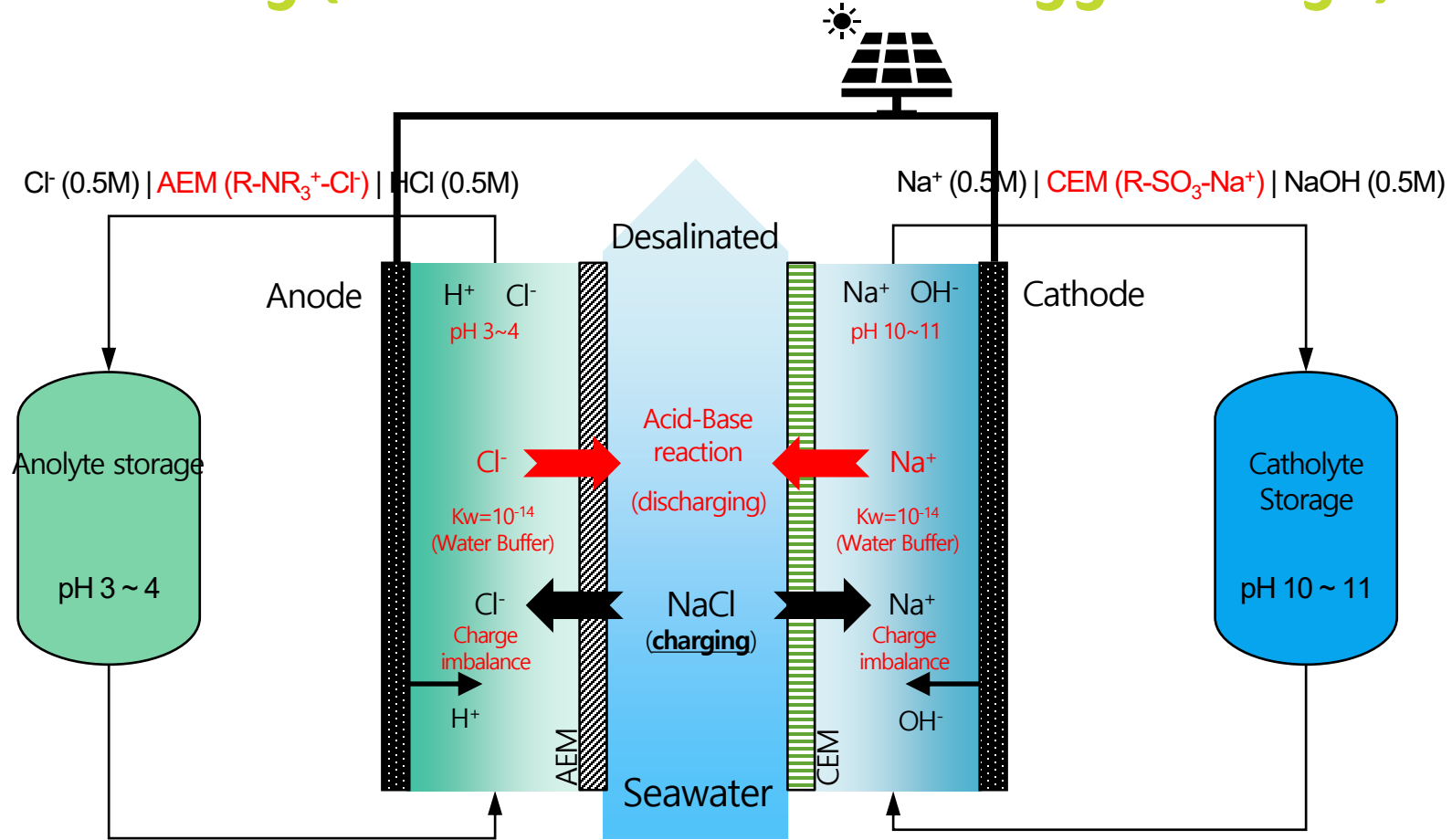
Reverse Electrodialysis (RED)

- LCOE: Levelized cost of energy
 $(\sum (\text{cost over lifetime}) / \sum (\text{electrical energy produced over lifetime}))$

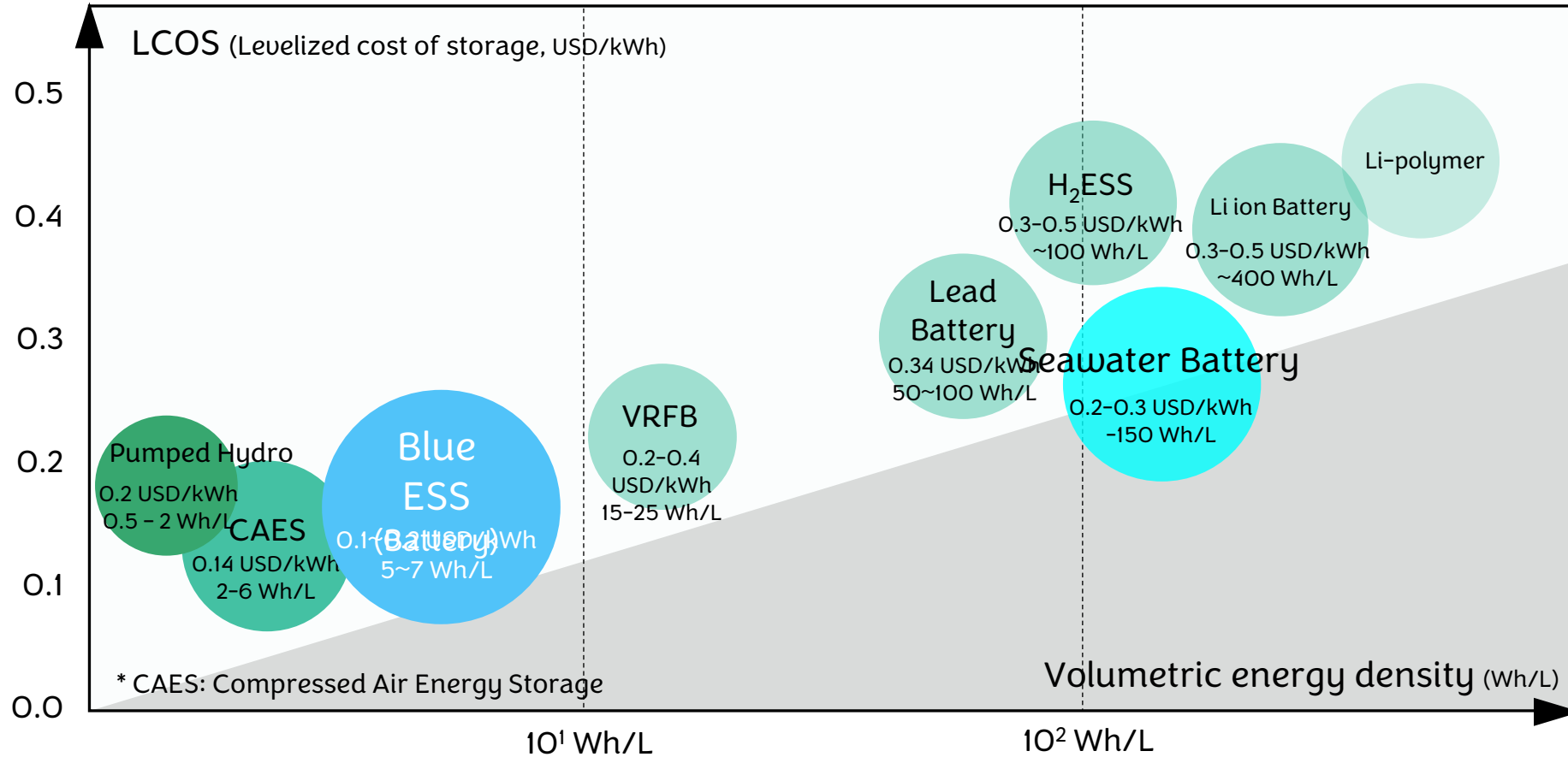
| Categories | CO ₂ emission [gCO ₂ -e/kWh] | LCOE [\$/kWh] | Availability (Stability in Power-Grid) | Efficiency [%] | Land-use [m ² /MW] |
|-------------------------|--|--|--|------------------------|--|
| Biomass | 230 - 740 | 0.07-0.18 | Occasional | 30~35 | - |
| Hydro | | 0.05-0.15 | Stable | < 80 | 78,300 (Commercial Dam) |
| Geothermal | 38 | 0.08-0.12 | Not stable (ESS essential) | 10~20 | - |
| Photovoltaic (PV) | 41-48 | 0.07-0.22 | Not stable (ESS essential) | 8~15 (S. Korea: 13.5%) | ~15,000 |
| Solar (Thermal) | 27 | 0.12 | Not stable (ESS essential) | 40~60 | 40,000 |
| Wind turbine (WT) | 11-12 | On-shore: 0.05-0.14 Off-shore: 0.1-0.2 | Not stable (ESS essential) | 25~54 | 15,000 -30,000 |
| Marine (tidal, wave) | 10-20 | - | Occasional | < 80 | 543 (including deck and lake: 80 km ²) |
| Salinity gradient power | 18 | Wastewater: 0.2– 0.3 <u>Brine: 0.05 – 0.1</u> | Stable (No ESS) | 30~40 | 500~3,000 |



Principle: Blue Battery (Seawater-based Energy Storage)



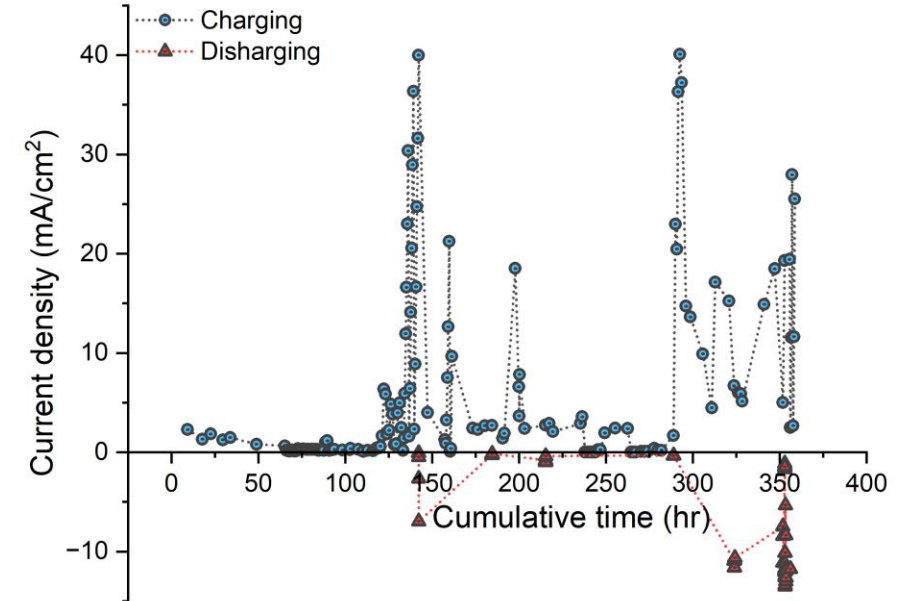
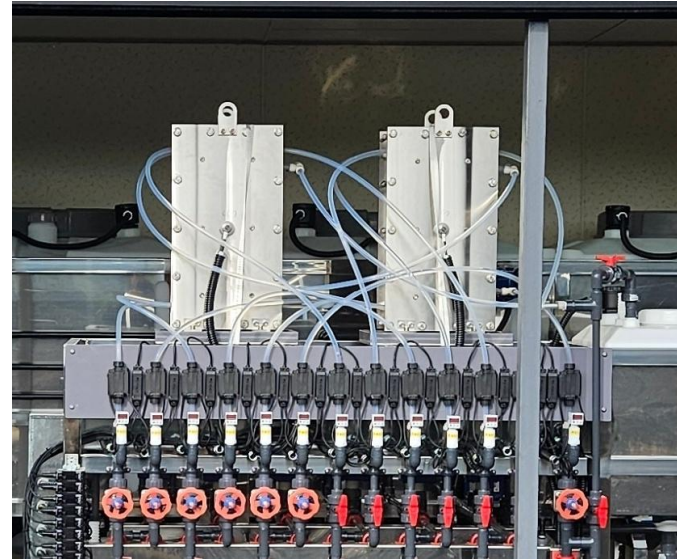
Blue Battery: the cheapest battery



Blue Battery: Lab-scale test



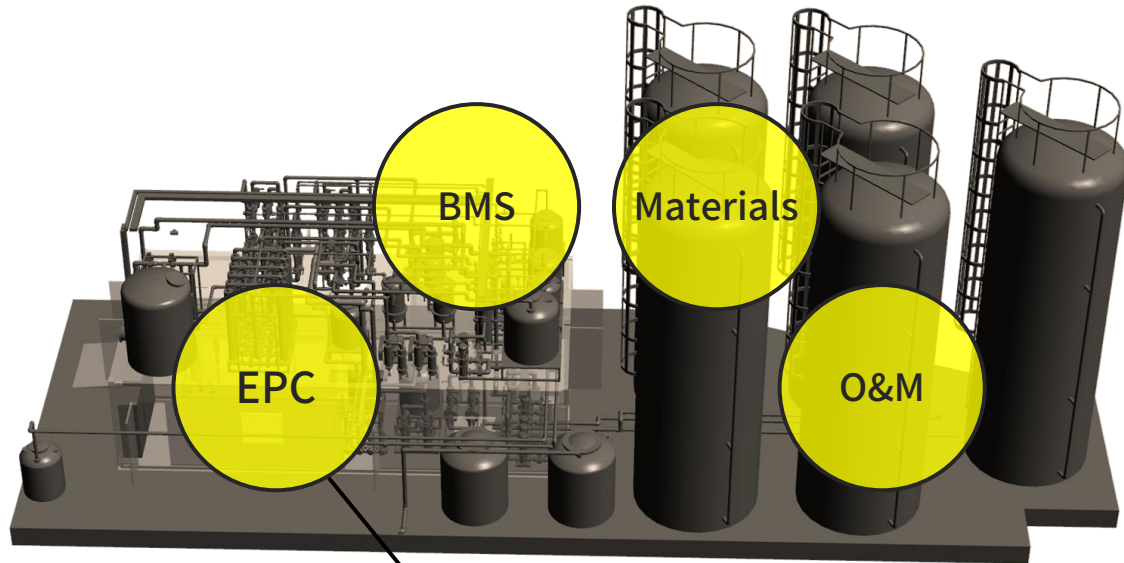
Blue Battery: Pilot-scale (kW) test (@Jeju Global Research Center)



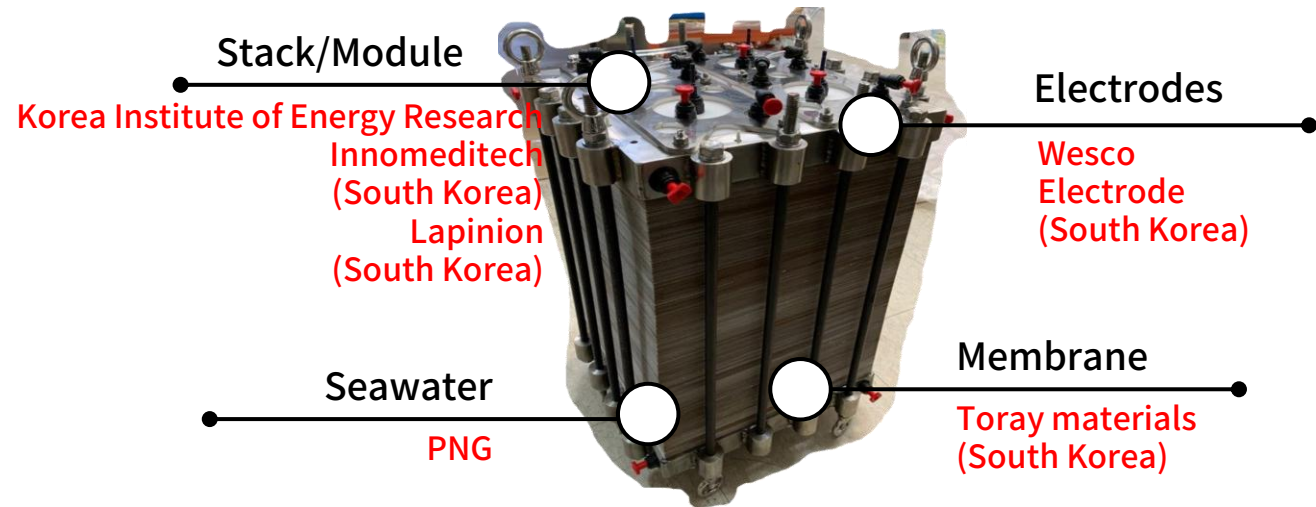
- For 30 days, blue battery system was operated without significant issue.
- Power source: PV + Grid (3:7)
- Battery: 1 kW / 10 kWh (charging time > 10 hrs)



Blue Battery: Pilot-scale (kW) test (@Jeju Global Research Center)

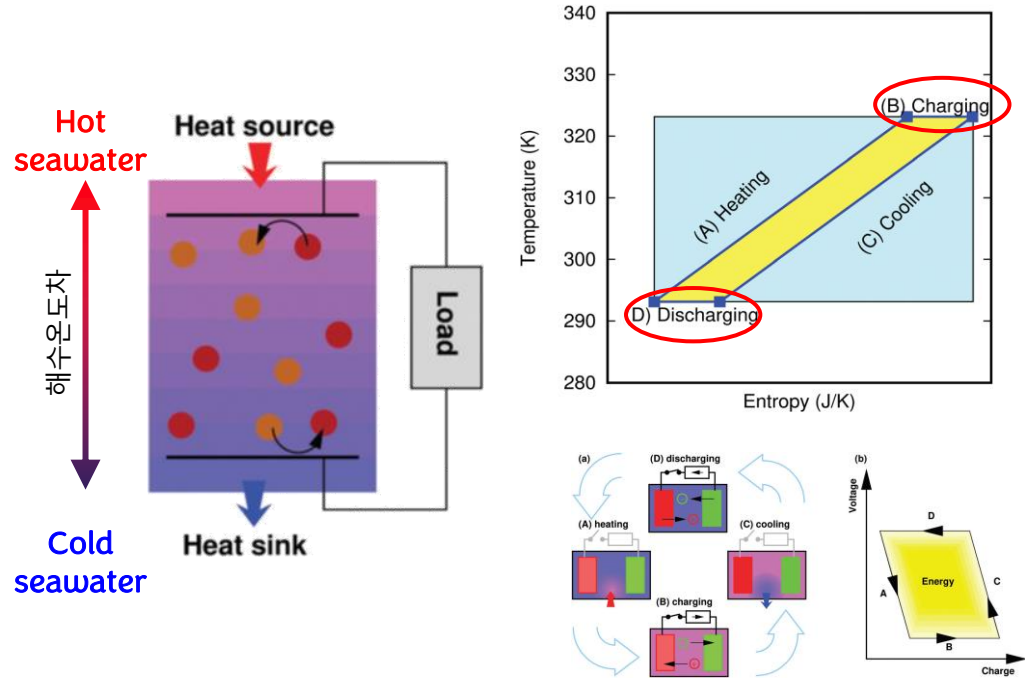


RED (South Korea)
Korea Institute of Energy Research
Samsung Engineering

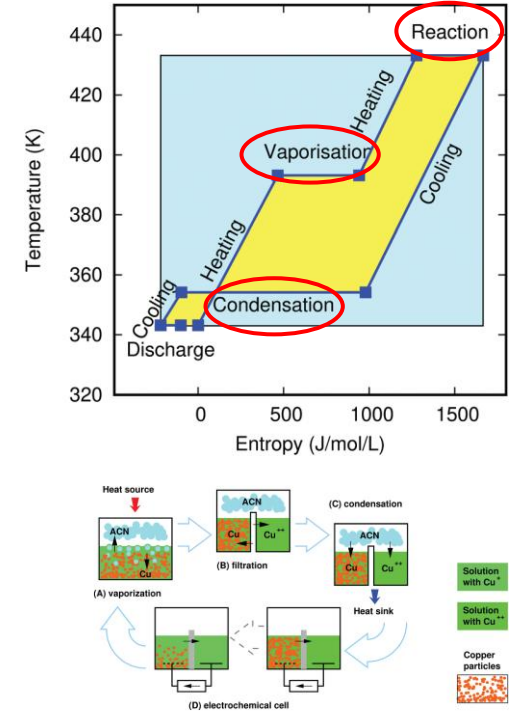
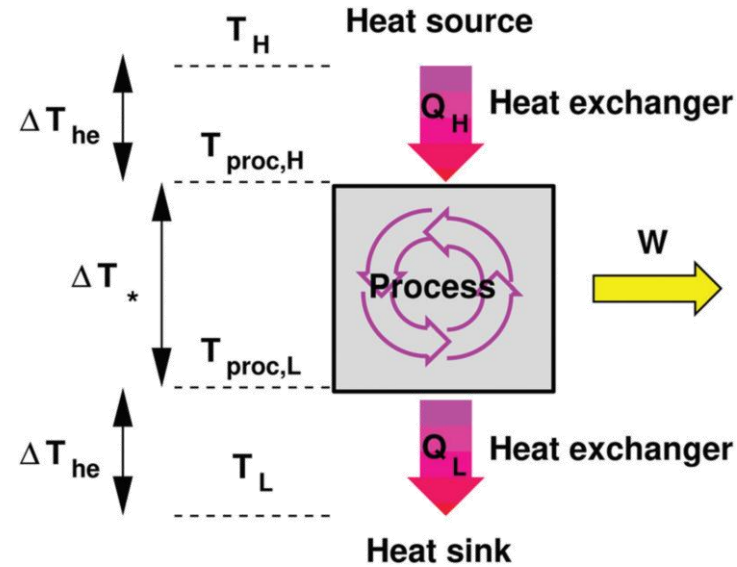


Principle: Electrochemical Ocean Thermal Energy Conversion

Electrochemical Heat Engine (Thermally Regenerative Electrochemical Cycle, TREC)

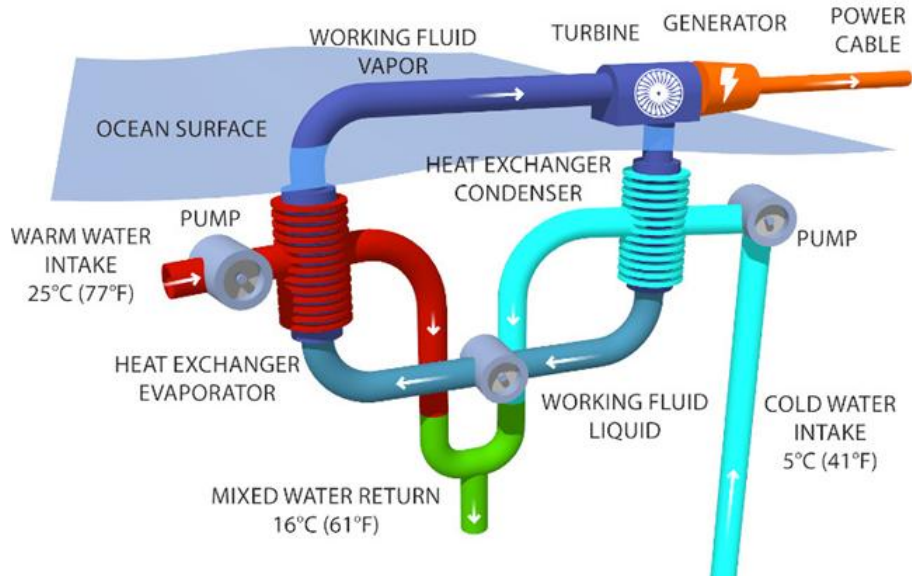


Thermally Regenerative Battery (TRB): Reaction + Phase change (energy storage)



Principle: e-OTEC

Conventional (mechanical) OTEC

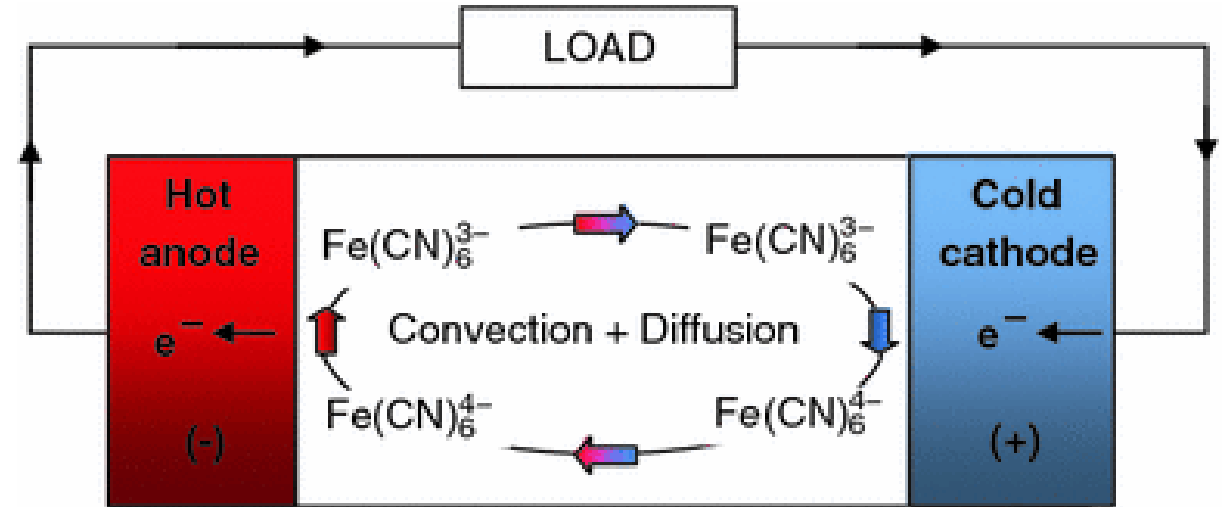


How: Running Turbine to generate electricity

Problem: Low heat efficiency (2.5 ~ 3.0%)

High capacity factor → Hard to commercialization

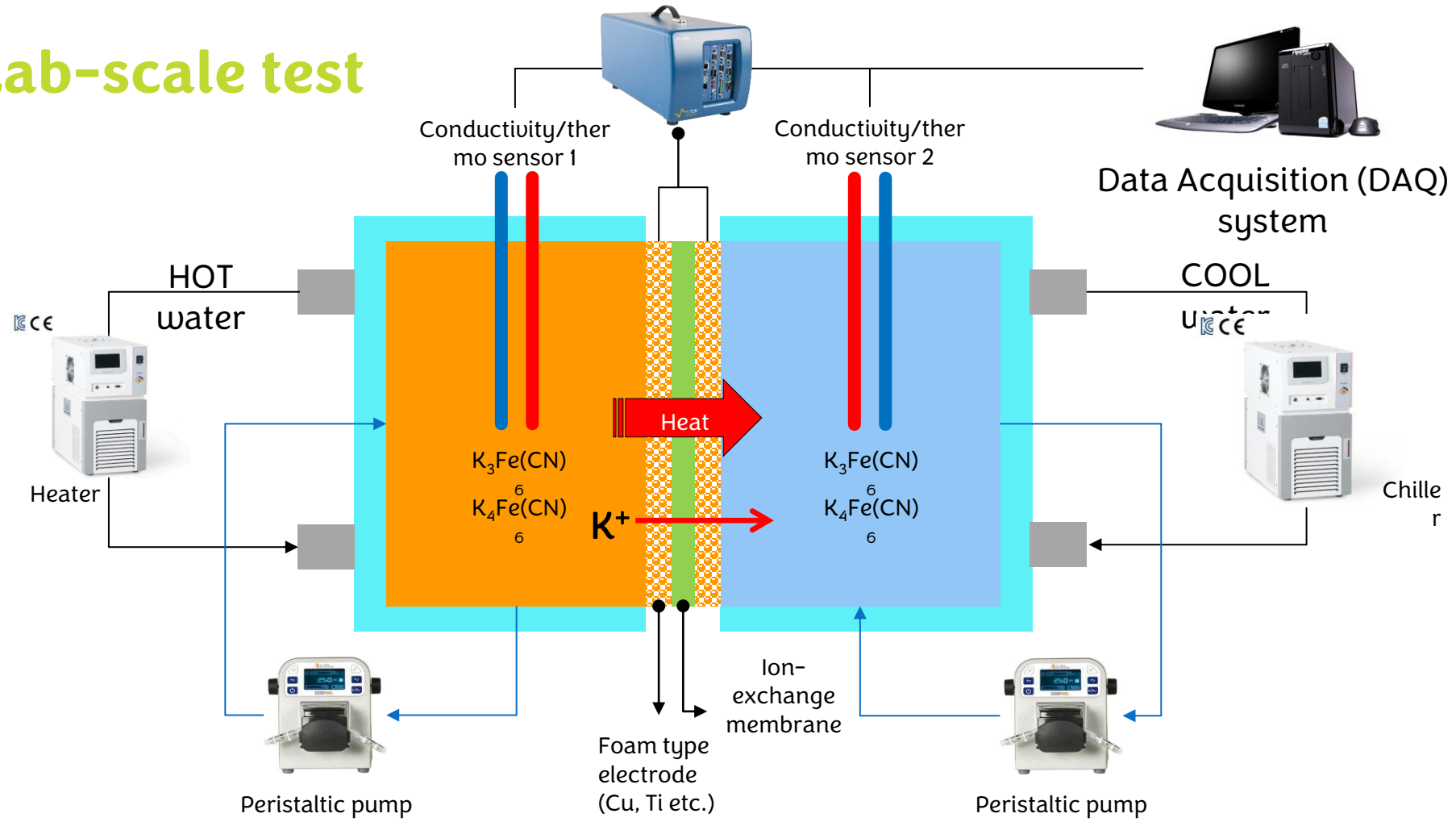
Electrochemical OTEC



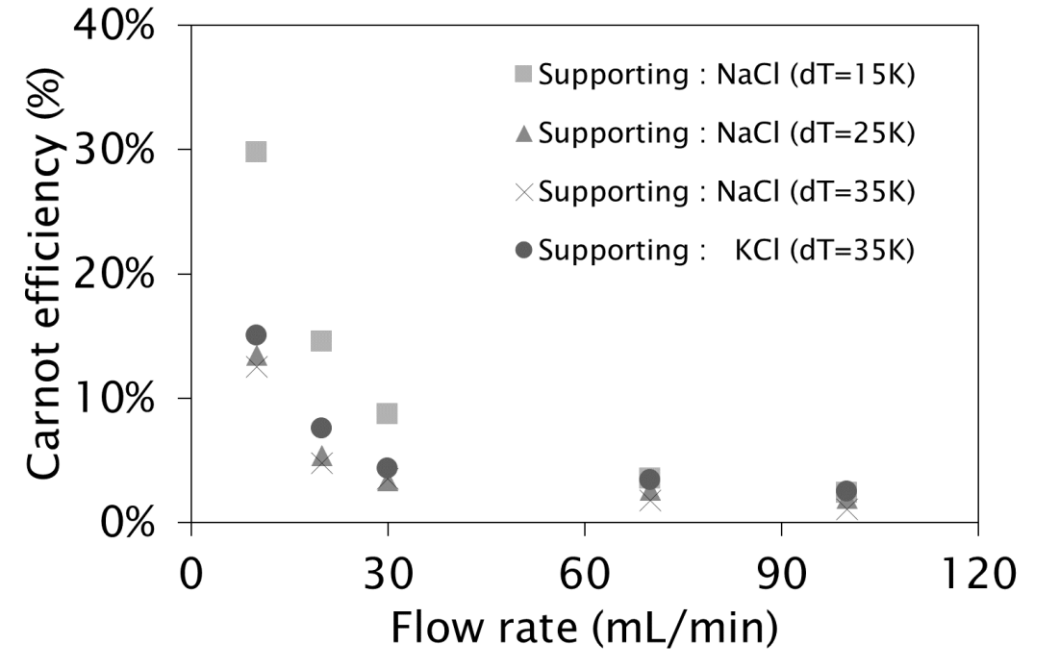
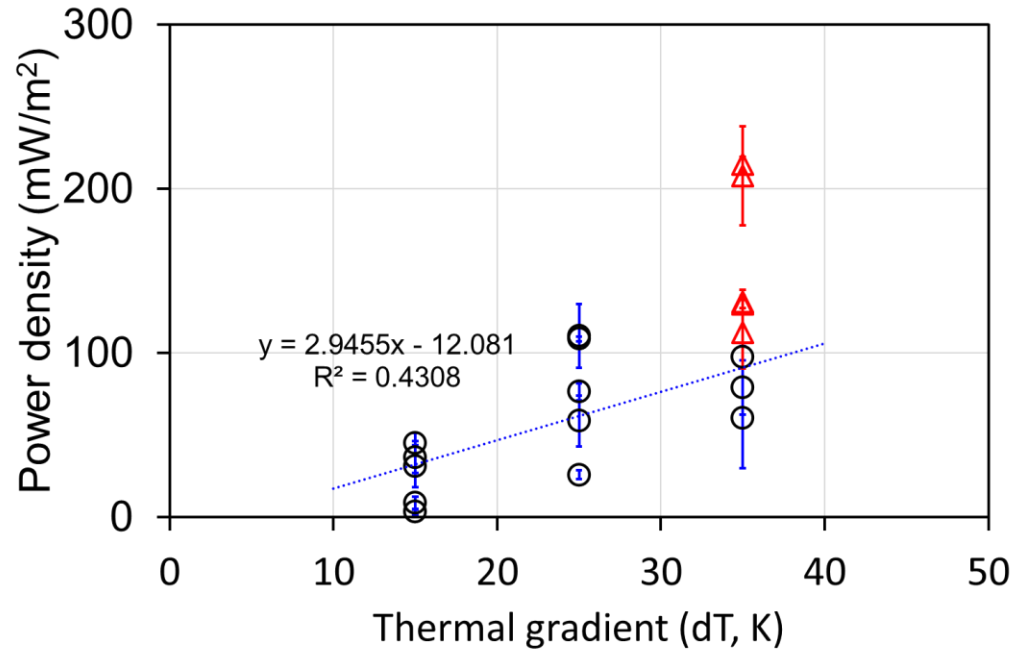
How: Using electrochemical reaction to generate electricity (High efficiency 10 ~ 15%)

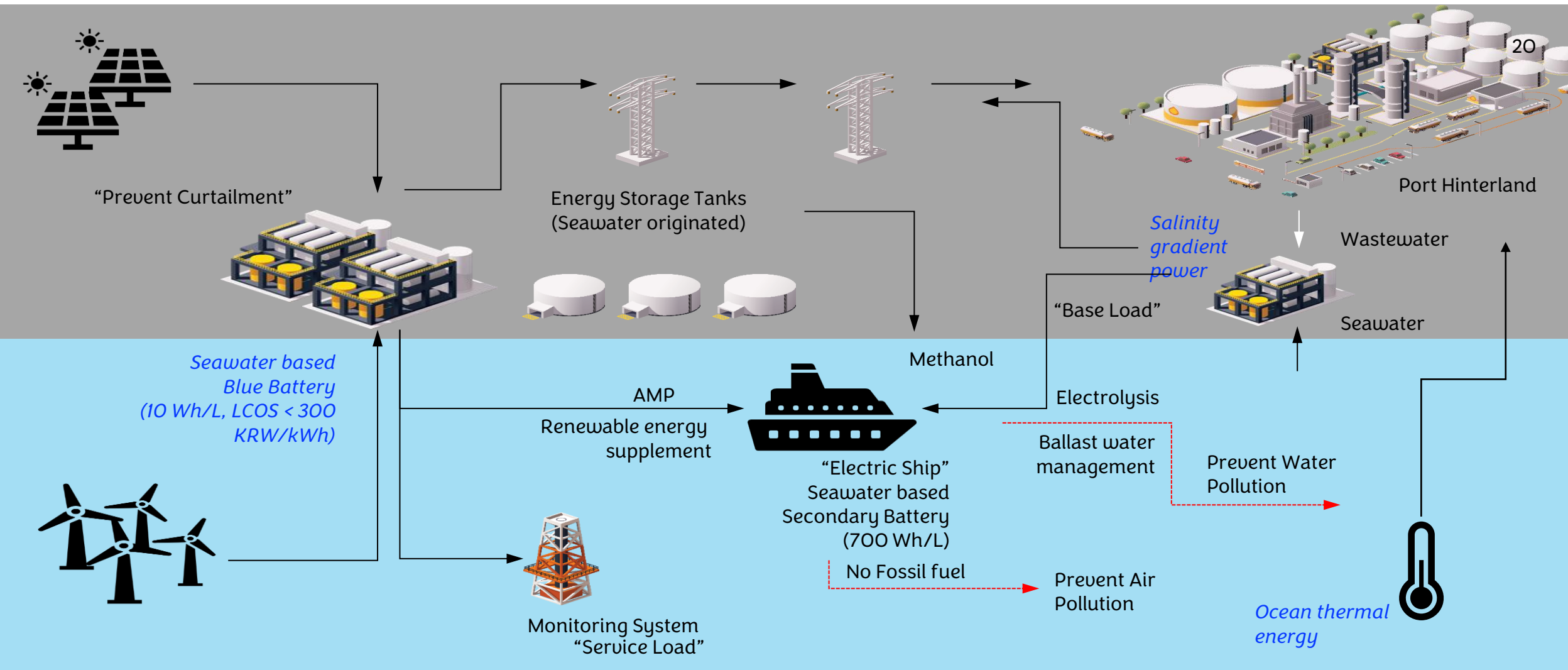
Low capacity factor → Easy to commercialization

e-OTEC: Lab-scale test



e-OTEC: Lab-scale test

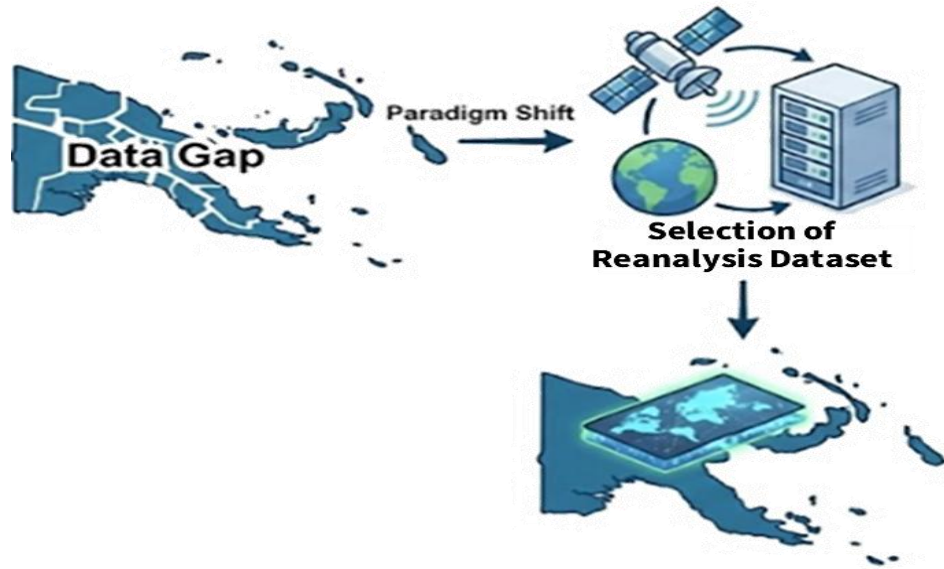




Estimation of energy potential in PNG

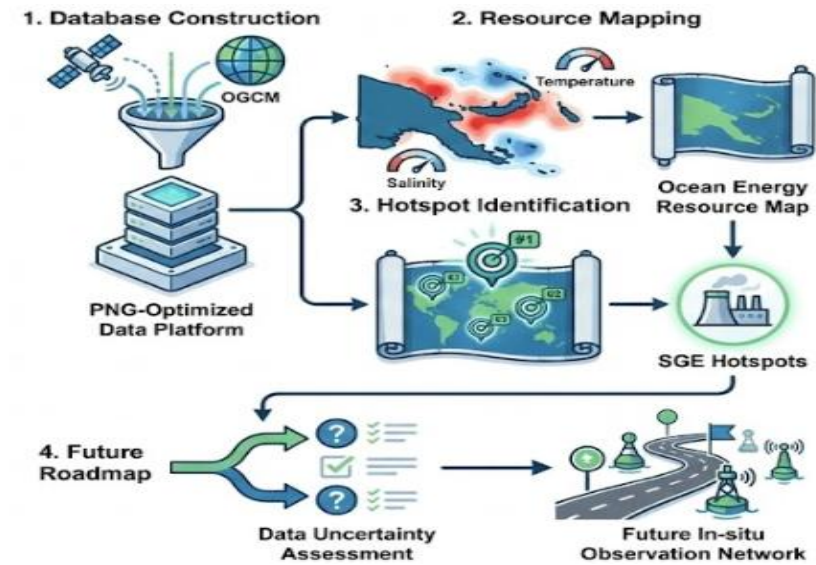


Potential assessment using satellite



Primary Goal: Bridging the Data Gap & Building the First Foundation

- Resolve PNG's chronic data scarcity by alternative data sources (i.e., Reanalysis dataset).
- Establish the scientific database for ocean energy assessment.
- Aim to produce "pre-investment grade" information to reduce uncertainty and attract future investment.



Specific Objectives

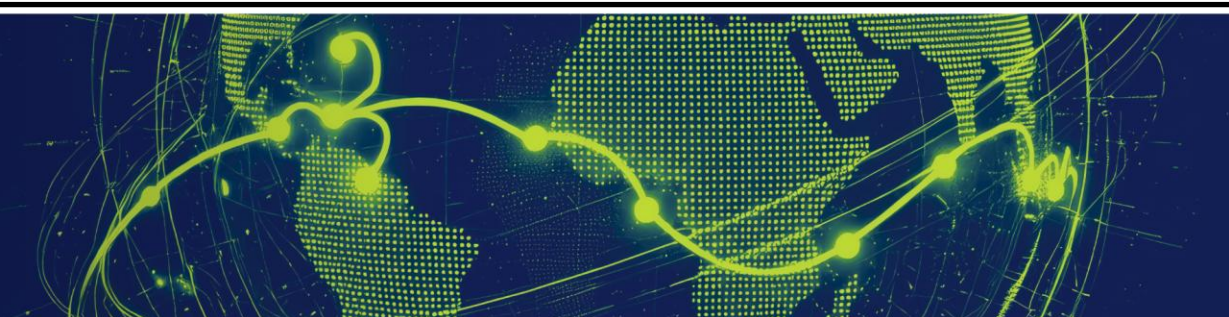
- **Build PNG-Optimized Database:** Collect and standardize diverse OGCM data (i.e., Reanalysis dataset) to create an analysis-ready platform from 2024 to 2025.
- **Quantify Spatiotemporal Variability:** Analyzing time-series of key variables (Sea Temp., and Salinity) over PNG
- **Provide Scientific Evidence:** Identifying hotspots for technologies (SGE) based on analysis.
- **Assess Uncertainty & Propose Roadmap:** Clarify data limitations and suggest a strategic roadmap for a future in-situ observation network.



Salinity gradient energy potential

Estimation

| Category | River location | Flows in (m3/s) | | | Flows in (m3/s) | | | Energy capacity [kWh/day] (specific energy = 0.22 kWh/m3, practical energy efficiency 31%) | | | (Available) Power capacity [kW] (opening hour: 22 hrs, maintenance: 1 hrs/day, ramp-up: 30 min - 1 hrs) | | | Equivalent power (Capacity Factor: 15%) |
|-------------------------------|----------------|-----------------|--------|----------|-----------------|---------------|----------------|---|----------------------|---------------------|--|----------------------|---------------------|--|
| | | Q_min | Q_mean | Q_max | Q_min | Q_mean | Q_max | Energy Capacity_min | Energy Capacity_mean | Energy Capacity_max | Energy Capacity_min | Energy Capacity_mean | Energy Capacity_max | |
| | | m3/s | m3/s | m3/s | m3/day | m3/day | m3/day | kWh/day | kWh/day | kWh/day | kW | kW | kW | kW |
| Kempwelch river | Bannon bridge | 12.34 | 117.75 | 1,049.73 | 1,066,262.40 | 10,173,772.80 | 90,696,672.00 | 234,577.73 | 2,238,230.02 | 19,953,267.84 | 10,662.62 | 101,737.73 | 906,966.72 | 6,046,444.80 |
| Angabunga | Yaiufa bridge | 7.79 | 113.80 | 1,164.53 | 672,969.60 | 9,832,406.40 | 100,615,392.00 | 148,053.31 | 2,163,129.41 | 22,135,386.24 | 6,729.70 | 98,324.06 | 1,006,153.92 | 6,707,692.80 |
| Vanapa | Peto island | 20.97 | 138.78 | 1,982.59 | 1,812,067.20 | 11,990,764.80 | 171,295,776.00 | 398,654.78 | 2,637,968.26 | 37,685,070.72 | 18,120.67 | 119,907.65 | 1,712,957.76 | 11,419,718.40 |
| Brown | Karema Bridge | 21.88 | 84.81 | 588.66 | 1,890,000.00 | 7,327,843.20 | 50,860,137.60 | 415,800.00 | 1,612,125.50 | 11,189,230.27 | 18,900.00 | 73,278.43 | 508,601.38 | 3,390,675.84 |
| Markham (would be updated) | Road Bridge | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | 1,197,085.82 | 8,651,453.18 | 90,962,955.07 | 54,412.99 | 393,247.87 | 4,134,679.78 | 27,564,531.84 |



E-OTEC energy potential

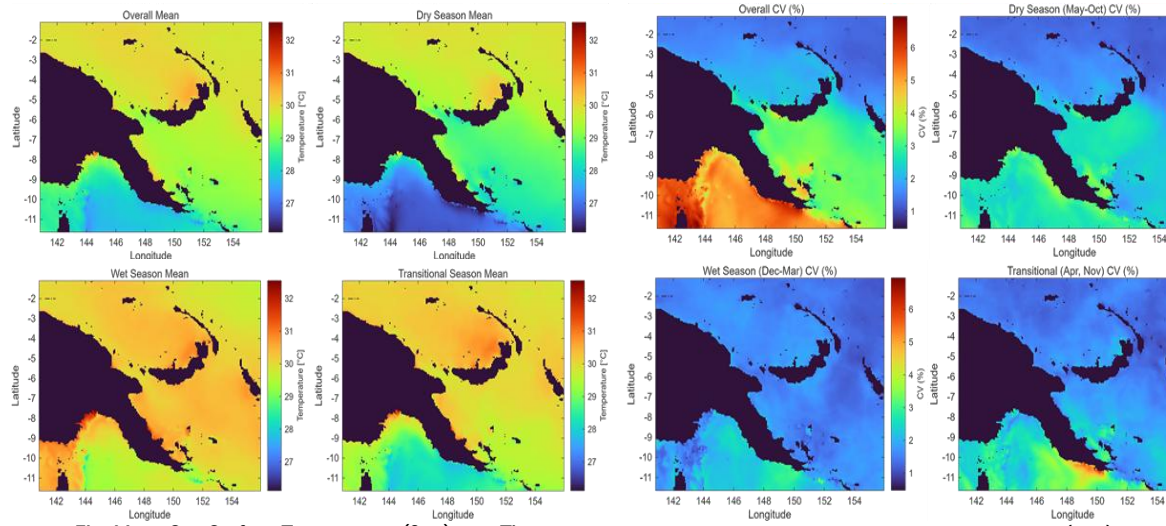


Fig. Mean Sea Surface Temperature (0 m) over Three Season at PNG

Fig. CV Maps of Sea Surface Temperature (0 m) over Three Season at PNG

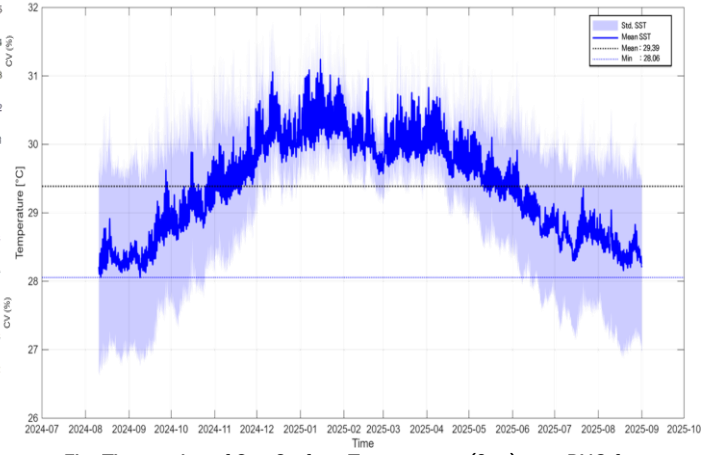


Fig. Time series of Sea Surface Temperature (0 m) over PNG from 2024.08 to 2025.08

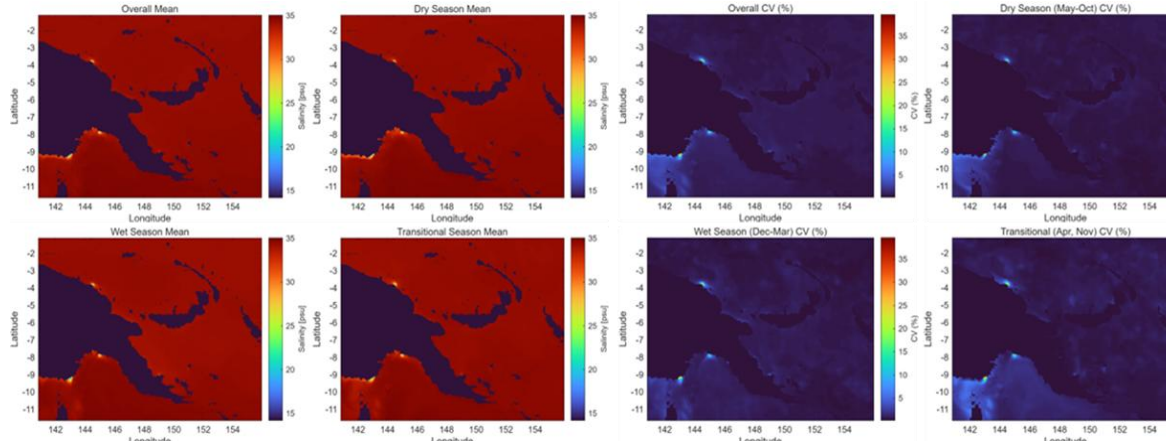


Fig. Mean Salinity (0 m) over Three Season at PNG

Fig. CV Maps Salinity (0 m) over Three Season at PNG

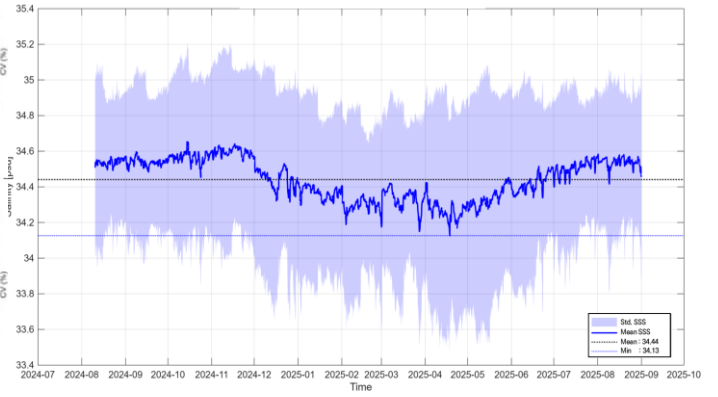
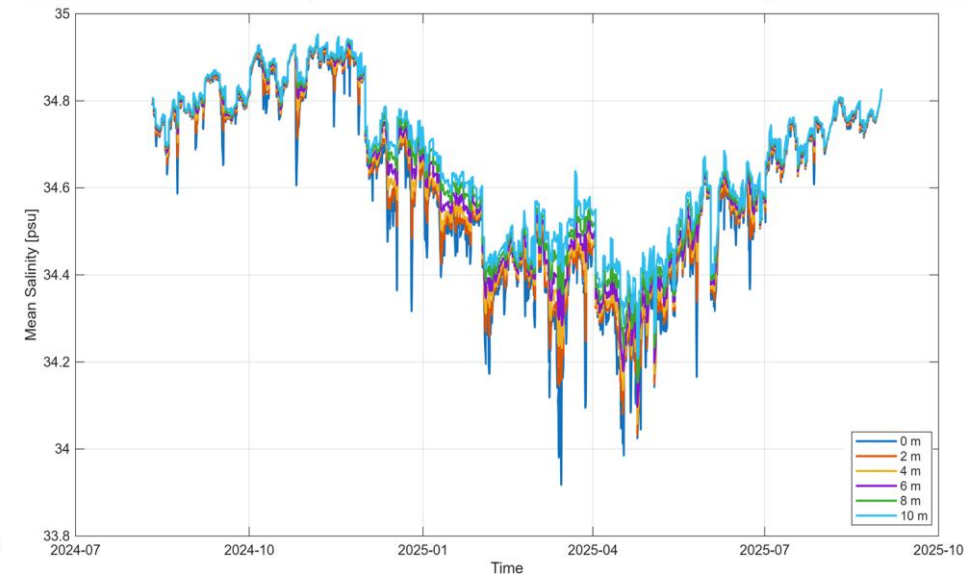
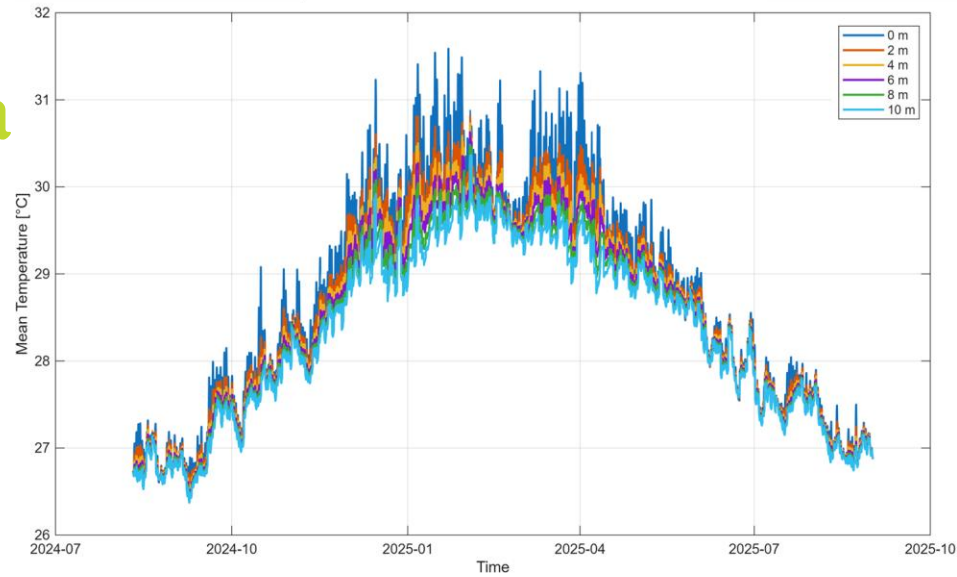


Fig. Time series of Salinity (0 m) over PNG from 2024.08 to 2025.08



Depth condition



Key Findings: Vertical Stability at 10 m

- **Temperature Buffering** : While the surface (0 m) shows high diurnal variation due to solar heating and cooling, the 10 m depth is perfectly buffered from these daily cycles. This minimizes thermal stress on SGE membranes.
- **Salinity Protection** : During the wet season (Dec-May), surface salinity drops drastically and fluctuates violently due to freshwater influx. However, the 10 m depth remains stable (maintaining a minimum of 34.4 PSU), protected by a strong halocline.

Conclusion

- **Optimal Location**: Port Moresby coastal waters offer an ideal vertical profile for SGE operations.
- **Critical Design Requirement**: Seawater intake must be installed at a depth of 10 m or deeper.
- **Expected Impact**: Ensures the secure supply of stable-temperature and consistent high-salinity seawater, which is decisive for the plant's economic viability, efficiency, and long-term durability.

| | Salinity Gradient Power (in particular, Reverse Electrodialysis) | Electrochemical Ocean Thermal Energy Conversion (e-OTEC) |
|-----------------------|--|--|
| Gross potential | <i>The total average flow rate of the four target rivers reaches approximately 455 m3/s (0.75 kWh/m3)</i> | <i>Very high</i> |
| Theoretical Potential | Analysis: The total average flow rate of the four target rivers reaches approximately 455 m3/s. Theoretically, this equates to 1.2 GW, representing an immense energy reserve comparable to a nuclear power plant. | <i>Revolutionary increase</i> Conventional: (dT=19°C) Carnot efficiency 6% → Practical system efficiency: 3% e-OTEC: (dT<20°C) ~20% <i>: stable power generation becomes theoretically possible year-round, regardless of the seasonal cooling (down to 27°C) observed in the southern waters (Port Moresby) due to the Southeast Trade Winds.</i> |
| Technical potential | High feasibility 1. This potential applies the efficiency of currently commercializing membrane technologies (~30%) (Gross potential) x (System efficiency) 2. Approximately, 368 MW of power generation is technically feasible. | <i>High feasibility</i> The technological barrier related to the Cold Water Pipe (CWP), which is the biggest challenge in OTEC construction, is drastically lowered. 1. Reduced intake depth: (1,000 m → 200 m): <i>There is no need to lower pipes to deep sea levels. Intake is possible at a relatively shallow depth of 200 m, reducing pipeline length and installation difficulty by more than 80%</i> 2. System downsizing <i>Thanks to the high efficiency, the required seawater flow rate to generate the same amount of power is significantly reduced. This decreases the parasitic load and allows for smaller heat exchanger and piping.</i> |
| Economic potential | | <i>High Economic Viability</i> 1. CAPEX reduction: The cost of seawater intake pipeline, which accounts for 40-50% of OTEC construction costs, is drastically reduced due to the shortened depth (200 m) 2. Infrastructure connectivity: The project becomes viable near Port Moresby, which has the highest power demand and existing grid Infrastructure. |



Future Works to progress the TA

1. Preparation of Pre-feasibility test – potentially lead to full feasibility study, including EIS, FPIC, and other required power development studies, etc.;
2. Collaboration between PSC members to prepare a SCI journal for publication – Title: “Potential of marine energy in PNG”.
3. KIER to provide online assistance – on operating reverse electrodialysis with UPNG and PNG UNITECH students.
4. MOU with KIER – (1) Joint MOU with CCDA, NEA and KIER; (2) MOU with National Institute of Standards and Industrial Technology to develop technical standards for the salinity gradient RED energy generation system – potentially for the region.
5. Internship program for PNG students to study in Korea Institute of Energy Research.



Thank you for your attention!

