



# Design Innovation of a Solar-Powered Seawater Purification Device to Support Science Learning in Coastal Areas

Mitri Irianti<sup>1\*</sup>, Ernidawati<sup>1</sup>, Wilda Novianti<sup>1</sup>, Zuhdi Ma'ruf<sup>1</sup>, Zulhelmi<sup>1</sup>, Naila Fauza<sup>1</sup>, Idris<sup>2</sup>, Abdul Hamid Sinaga<sup>1</sup>, Rahmi Hidayah<sup>1</sup>, Dhuha Fatihul Burhan<sup>1</sup>

<sup>1</sup> Physics Education Study Program, Faculty of Teacher Training and Education, Universitas Riau, Pekanbaru, Riau, Indonesia.

<sup>2</sup> Institute for Contemporary Socio-Political Studies, Pekanbaru, Riau, Indonesia.

Received: September 19, 2025

Revised: October 24, 2025

Accepted: November 25, 2025

Published: November 30, 2025

Corresponding Author:

Mitri Irianti

[mitri.irianti@lecturer.unri.ac.id](mailto:mitri.irianti@lecturer.unri.ac.id)

DOI: [10.29303/jppipa.v11i11.12897](https://doi.org/10.29303/jppipa.v11i11.12897)

© 2025 The Authors. This open access article is distributed under a (CC-BY License)



**Abstract:** Coastal communities in Indonesia face limited access to clean water because water sources are dominated by seawater and the availability of fresh water is extremely limited. This problem creates a need for innovative and sustainable solutions that can be applied in everyday life and utilized in science learning. This study aims to design and test the feasibility of a solar panel-based seawater purifier as a contextual physics learning medium and a means of providing clean water for coastal communities. The research method used is Research and Development (R&D), conducted through the stages of needs analysis, design, prototyping, expert validation, and limited field trials. Data collected includes expert validation results, practicality assessments by teachers and students, and empirical measurements of water quality such as pH, TDS, salinity, specific gravity, ORP, and EC. Qualitative findings from the validators indicate that this tool has good functionality, is relevant for learning, is easy to use, and is safe to operate. The results show an average validity of 3.73 (very valid) and practicality of 3.60 from students and 3.86 from teachers (very practical category). Water quality tests showed a pH of 6.83, TDS of 124 ppm, which meets WHO standards (TDS < 500 ppm), salinity of 0.01%, specific gravity (SG) of 1.00, ORP of 224 mV, and EC of 0  $\mu$ S/cm, indicating that the water is suitable for consumption. Thus, the aim of the research is to produce a valid, practical seawater purifier and provide a sustainable alternative solution for the clean water needs of coastal communities.

**Keywords:** Coastal areas; Design innovation; Science learning; Seawater purification; Solar panels

## Introduction

Indonesia, as an archipelagic nation, has the second-longest coastline in the world. This geographical location makes coastal areas vital to people's lives, serving as residences, centers of economic activity, and educational centers. One of the classic problems facing coastal communities is limited access to clean water (Sembiring et al., 2023). Limited freshwater resources are insufficient to meet demand, while abundant seawater

cannot be directly utilized due to its high salinity (McPeake et al., 2025). This problem impacts health and social aspects, as well as the science learning process in coastal schools, which require practical media based on real-world phenomena in the surrounding environment.

Clean water is a basic human need, yet its availability is increasingly limited due to population growth, rapid urbanization, and the significant impacts of climate change (Chebil et al., 2024). Over 97% of the Earth's water is seawater, while usable freshwater is

### How to Cite:

Irianti, M. ., Ernidawati, Novianti, W., Ma'ruf, Z., Zulhelmi, Fauza, N., ... Burhan, D. F. (2025). Design Innovation of a Solar-Powered Seawater Purification Device to Support Science Learning in Coastal Areas. *Jurnal Penelitian Pendidikan IPA*, 11(11), 1006-1020. <https://doi.org/10.29303/jppipa.v11i11.12897>

scarce, leading many regions around the world to experience a clean water crisis (Chebil et al., 2024).

To overcome these limitations, one widely developed solution is desalination technology, the process of converting seawater into usable freshwater (Alrowais et al., 2022). Desalination technology is divided into two main types: heating (thermal) methods and membrane methods (Dimitriou et al., 2025). Thermal methods such as multi-stage flash (MSF) and multi-effect distillation (MED) have been used for a long time, but they require very high energy consumption and pose environmental problem (Alrowais et al., 2022).

On the other hand, membrane technologies such as reverse osmosis (RO) are gaining popularity due to their greater energy and operational cost savings and now account for approximately 69% of global desalination capacity (Marx et al., 2025). However, RO also faces significant challenges, including fouling and scaling, where dirt, microorganisms, or salts accumulate on the membrane and degrade system performance (Philibert et al., 2024). Fouling leads to decreased water quality, increased energy requirements, and higher maintenance costs (Shouman et al., 2024). Research has even shown that calcium sulfate deposits are difficult to remove even with the use of antiscalants, resulting in reduced system performance and water quality (Rezaei et al., 2020).

To mitigate these issues, researchers are developing innovations in membrane design and materials. For example, the addition of Surface Modifying Macromolecules (SMM) to hollow fiber PVDF membranes has been shown to improve salt filtration performance by up to 99.9% (Purwanto et al., 2021). Furthermore, the use of ZrO<sub>2</sub> nanocomposites in RO membranes can also increase membrane resistance to fouling (Alaswad et al., 2025). Membrane distillation (MD) technology, particularly vacuum membrane distillation (VMD), is also attracting increasing attention due to its ability to produce high-quality water with lower energy consumption (Idrees et al., 2023). Another study found that PVDF-PTFE composite membranes can provide stable results in both seawater and brackish water (Madupathi et al., 2024).

In addition to membrane material development, several other technologies also offer improved energy efficiency. Multistage electro dialysis, for example, can reduce energy consumption by up to 3.6 kWh/m<sup>3</sup>, making it more economical than traditional methods (Doornbusch et al., 2019). Meanwhile, the integration of seawater reverse osmosis with pressure-retarded osmosis (SWRO-PRO) has been shown to reduce specific energy consumption by up to 41% (Marx et al., 2025).

Another crucial effort is integrating desalination technology with renewable energy, particularly solar energy, which is abundant in arid regions most

vulnerable to water crises (Madhuri et al., 2025). The use of solar energy in air-conditioning and desalination systems has been shown to reduce energy consumption by up to 60% compared to conventional systems (Yosry et al., 2024). Furthermore, solar-powered desalination is considered more environmentally friendly because it can reduce carbon emissions (Goosen et al., 2023).

Another interesting innovation is the bio-electrochemical method using Microbial Desalination Cells (MDC), which not only produces clean water but also treats wastewater and generates electricity in a single system (Sikder et al., 2024). Furthermore, the humidification-dehumidification (HDH) method with fogging also holds promise, as it can reduce clean water production costs to just USD 0.0088 per liter (Nabil et al., 2025).

Clean water plays a crucial role in supporting the learning process, particularly in science, which emphasizes practical and experimental aspects. Real-world problems related to clean water needs can serve as entry points for learning to understand various scientific concepts, such as the water cycle, heat transfer, renewable energy, and simple engineering technologies. Therefore, developing innovations that connect the community's need for clean water with educational needs is crucial. The abundant use of solar energy in coastal areas offers a significant opportunity to introduce simple, environmentally friendly, and low-cost seawater purification technology (Curto et al., 2021). In addition to providing a solution to community needs, this innovation also serves as a contextual learning tool that emphasizes the relationship between scientific theory and the application of technology in everyday life (Shatat et al., 2014).

This clean water issue can be used as a relevant learning context, as it concerns the community's fundamental needs. Through this real-life issue, the public can learn various scientific concepts, such as the water cycle, evaporation, condensation, and the use of renewable energy. Thus, local challenges facing coastal areas can be transformed into opportunities to introduce problem-based learning models that encourage students and the general public to think critically and creatively in finding solutions.

Utilizing solar energy offers a potential solution to these challenges. The intensity of sunlight in coastal areas is very high year-round, making it a potential renewable energy source (Ibrahim, 2022). The process of purifying seawater using solar panels utilizes the simple yet effective principles of evaporation and condensation. This innovation has the potential to produce clean freshwater while also providing a contextual learning medium that connects theory with the application of technology in everyday life (Wu et al., 2021).

Modern desalination technology has developed, but it generally requires significant costs and complex infrastructure (Pan et al., 2022). This makes it difficult for coastal communities to access. A solar panel-based seawater purifier can be designed in a simple, low-cost, and environmentally friendly way. The use of local materials allows schools and communities to build and operate it independently.

The effectiveness of this technology has been proven through research conducted by Hadi et al. (2024). The study compared the quantity of purified water from three tanks with different configurations. The results showed that the tank with two heating elements produced the most fresh water, namely 1,984 ml, higher than the tank with one element (1.198 ml) and without elements (820 ml). The quality of the resulting water was also good, indicated by a pH of 7.07 and a TDS of 78 ppm, which is safe for consumption. These findings indicate that the use of solar panels in seawater purification is not only technically feasible but also has great potential as a science learning medium in coastal schools.

In the context of learning, a project-based learning approach is highly relevant for utilizing this seawater purification technology. Through designing, building, and testing the device, the community can gain real-life learning experiences. These activities not only hone understanding of scientific concepts but also cultivate critical thinking, creativity, and collaboration skills. Thus, learning is oriented not only toward cognitive knowledge but also toward developing 21st-century skills needed in everyday life.

The benefits of this innovation extend beyond education. The clean water produced can be directly used by coastal communities struggling to access freshwater sources. In other words, educational institutions developing this technology can serve a dual role: as learning centers and agents of social change (Wibowo et al., 2020). This demonstrates how education can have a tangible impact on the surrounding environment, aligning with the Sustainable Development Goals (SDGs), which emphasize the integration of quality education with meeting basic community needs.

In addition to providing practical benefits, this technology also has educational value in fostering environmental awareness. Through the implementation of solar-powered seawater purifiers, the public is introduced to the importance of renewable energy and the limitations of fossil fuels (Rahmani et al., 2022). This learning process fosters an understanding that technological choices have an impact on the environment. Therefore, the implementation of this innovation has the potential to produce a generation that is more concerned about preserving the earth and

oriented towards sustainable development (Yoshi et al., 2017).

The characteristics of coastal areas, which are rich in sunlight and yet face limited freshwater resources, reinforce the relevance of developing solar panel-based seawater purifiers. This technology can be integrated into various forms of general education, particularly in the areas of energy, material transformation, and environmental issues. By combining technical, educational, and social aspects, this innovation is not only a technical solution but also a strategy for building community awareness, skills, and independence. Therefore, the urgency of developing this technology is increasingly clear as an effort to address local challenges while strengthening the role of education in responding to global issues.

## Method

This study uses the Research and Development (R&D) method with a focus on developing a conceptual design for a solar panel-based seawater purifier that can be used to support science learning in coastal areas. This research is a Research and Development (R&D) study using the ADDIE (Analysis, Design, Development, Implementation, Evaluation) development model. The ADDIE model was chosen because it presents systematic and structured stages to produce a product that meets the expected goals, namely designing and developing an effective and efficient product (Mulyatiningsih, 2016).

The ADDIE model includes five stages, namely: (1) Analysis, which focuses on identifying problems related to the need for clean water in Gaung Anak Serka District; (2) Design, which is making an initial design for a seawater purifier as a learning medium; (3) Development, which is the process of making a tool according to the design that has been prepared; (4) Implementation, which is a step to test the use of the tool that has been developed; and (5) Evaluation, which aims to assess the quality and effectiveness of the resulting product.

However, this research only reached the development stage of a seawater purifier used as a learning medium for global warming for high school students. The research data consisted of two types: qualitative and quantitative. Qualitative data were analyzed descriptively, while quantitative data were obtained by comparing the results of the device's measurements with drinking water quality standards. In general, seawater has a salt content of around 33,000 mg/L, while brackish water ranges from 1,000–3,000 mg/L (Bekliu et al., 2025). Meanwhile, drinking water suitable for consumption must have a salt content below 400 mg/L. Therefore, treatment is necessary to reduce

the salt content of both seawater and brackish water to a safe threshold.

The quantitative data in this study are the results of empirical validation of the tool trials, with the aim of determining the level of measurement error compared

to the water consumption standards stipulated in (Ministry of Health, 2023). Mandatory Drinking Water Parameters according to Indonesian Minister of Health Regulation No. 2 of 2023 can be seen in Table 1.

**Table 1.** Mandatory Parameters for Drinking Water (Kementerian Kesehatan, 2023)

Parameter	Maximum Limit (Ministry of Health Regulation)	Unit
pH	6.5 - 8.5	-
Total Dissolved Solid (TDS)	< 300	mg/L
Salinity	Not specifically stated, usually < 0.5 ppt (fresh water)	ppt (%)
Temperature	Air temperature ± 3	°C
Specific Gravity (SG)	Not listed directly, used for water characterization (≈1.0 for pure water)	-
Oxidation Reduction Potential (ORP)	Not listed in the Minister of Health Regulation, used to assess the oxidation capacity of water (generally 250-400 mV for drinking water)	mV
Electrical Conductivity (EC)	Correlation with TDS (generally < 500 μS/cm for drinking water)	μS/cm
Color	≤ 10 TCU	TCU (True Color Unit)
Smell	Odorless	-

Qualitative descriptive data analysis was used to process qualitative data in the form of suggestions, criticisms, and comments from the validator. The analysis was carried out by grouping and describing the qualitative information obtained from the expert validation sheet. Quantitative descriptive analysis was used to process the expert validation results in the form of questionnaire scores (Prasetyo et al., 2017). Data were obtained through questionnaires filled out by material expert and media expert validators. In this study, three lecturers from the Physics Education Faculty of the University of Riau acted as expert validators. The analysis stage involved determining categories and scores for the validation instrument answers filled out by the validator using a Likert scale as shown in Table 2.

**Table 2.** Likert Scale Categories (Prasetyo et al., 2017)

Score	Category
4	Very good
3	Good
2	Bad
1	Very Bad

An assessment item is declared valid if all experts give a minimum score of 3. If the items on the questionnaire get a score of 1 and 2, they must be validated again until the items get a score of 3 or 4. Next, find the overall average of the instrument assessment sheet by comparing the number of scores obtained with the number of aspects assessed. Determination of the eligibility or validity criteria of a learning media is obtained by matching the total average with the validity category as shown in Table 3.

An assessment item is declared valid if all experts give a minimum score of 3. Meanwhile, learning media is declared valid if all items have been declared valid by all validators or a validity index of at least 3.00. The validity index and validity categories can be seen in Table 3.

**Table 3.** Validity Categories (Prasetyo et al., 2017)

Validity Index	Category
$3.50 \leq x \leq 4.00$	Very high
$3.00 \leq x \leq 3.50$	High
$2.00 \leq x \leq 3.00$	Low
$1.00 \leq x \leq 2.00$	Very low

Qualitative descriptive analysis was also used to process practicality data obtained from the field trial questionnaire. The instrument was administered to 29 students and two teachers to assess the ease, clarity, and attractiveness of the learning media. The assessment scores were scored using a Likert scale with categories as shown in Table 4.

**Table 4.** Practicality Likert Scale Categories (Nisa et al., 2023)

Score	Categories
4	Very Practical
3	Practical
2	Impractical
1	Very Impractical

The practicality results from students and teachers were analyzed by calculating the average for each statement. These averages were then matched against the practicality assessment categories, as shown in Table 5.

An assessment item is declared practical if all respondents (students and teachers) give a minimum score of 3. Meanwhile, learning media is declared practical if all items have been declared practical by all respondents or the practicality index is at least 3.00. The practicality index and practicality categories can be seen in Table 5.

**Table 5.** Practicality Categories (Nisa et al., 2023)

Validity Index	Category
$3.50 \leq x \leq 4.00$	Very Practical
$3.00 \leq x \leq 3.50$	Practical
$2.00 \leq x \leq 3.00$	Less Practical
$1.00 \leq x \leq 2.00$	Impractical

## Result and Discussion

The issue of clean water in coastal areas is a critical issue that directly impacts people’s quality of life. As an archipelagic nation with the second-longest coastline in the world, Indonesia faces significant challenges in meeting this basic need. Abundant seawater cannot be directly utilized due to its high salinity, while freshwater resources are extremely limited. This situation creates a dependence on external supplies, the availability of which is not always guaranteed. Therefore, practical and sustainable solutions are needed that are appropriate to the characteristics of the coastal environment.

One of the most significant potentials that can be harnessed is solar energy. Coastal areas generally experience high levels of sunlight year-round, opening up significant opportunities for environmentally friendly technologies. Utilizing solar energy to purify seawater into freshwater not only addresses a basic community need but also introduces innovative approaches to addressing resource constraints. The simple principles of evaporation and condensation can serve as the basis for developing small-scale desalination technology based on solar panels.

In a social context, the presence of solar panel-based seawater purification technology also has a significant impact. In addition to providing clean water, this device serves as a learning tool for the community, helping them understand the relationship between science, technology, and daily life needs. The water purification process can introduce scientific concepts such as the water cycle, heat transfer, and renewable energy. Thus, this technology is not only a technical solution but also a contextual learning tool for coastal communities at large.

To prove the effectiveness of this innovation, the study was conducted using Research and Development (R&D) methods. The research stages included needs identification, product design, prototype creation, limited trials, product revisions, and field testing.

### Analysis Stage

The initial stage of the research was to identify the problems facing coastal communities. Observations showed that limited freshwater availability is a major issue affecting daily life. Abundant seawater cannot be directly utilized due to its high salinity, while freshwater sources are extremely limited. The coastal geography, with its high year-round sunlight intensity, presents a significant opportunity to utilize solar energy as a solution for seawater purification (Wigati et al., 2018).

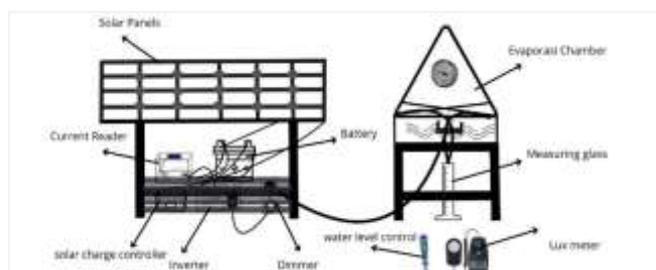
Appropriate learning media for demonstrating the application of abstract concepts are instructional props or experiments. With experimental media, students can more easily connect physics theory to real-world phenomena around them. Therefore, the development of a solar panel-based seawater purifier is not only relevant for supporting contextual physics learning but also provides insight into the use of renewable energy (Hadi et al., 2024).

### Product Design

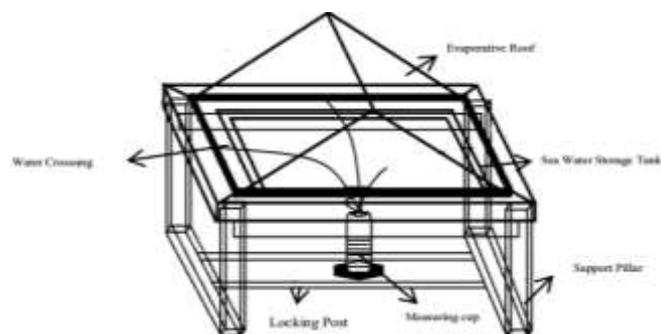
This solar panel-based seawater purifier is designed based on the principles of simplicity, efficiency, cost-effectiveness, and environmental friendliness. The system circuit is designed with coastal communities in mind, as well as ease of operation. The design utilizes abundant solar energy sources, combined with additional heating elements to accelerate the evaporation process.

The seawater purifier is designed to consist of three main components: an evaporation tank, a current reader circuit, and an inverter. The evaporation tank is shaped like a triangular prism with a height of 27.5 cm, a length of 57 cm, and a width of 57 cm, with a 35° tilt angle and a glass thickness of 0.5 cm. The evaporation tank consists of two main parts: an upper frame and a lower frame.

On the outermost part of the upper frame (the roof of the evaporation tank), a frame made of sol foam measuring 57 × 6 cm is installed. This sol foam frame serves to seal gaps where outside air may enter, ensuring that the evaporation tank only accommodates the hot air produced by the heating element, while the freshwater channel measures 57 × 6 cm. The design of the upper frame of the seawater purifier, measuring 57 × 57 cm, is shown in Figure 1.



**Figure 1.** Design of solar panel seawater purifier



**Figure 2.** Evaporation tank design of solar panel seawater purifier (Ernidawati et al., 2021)

To make the lower frame, 4 truss beams measuring 57 x 4 cm, 2 key beams measuring 57 x 4 cm, and 1 tension beam measuring 57 x 4 cm are required. The lower frame is also equipped with a measuring cup holder as a place to store fresh water, and a water hose that connects the water channel on the upper frame with the measuring cup, the lower frame design is as shown in Figure 2.

**Table 6.** Arduino Nano Pin Configuration

PIN Number	Pin Name
1	Digital Pin 1 (TX)
2	Digital Pin 0 (RX)
3 & 28	Reset
4 & 29	GND
5	Digital Pin 2
6	Digital Pin 3 (PWM)
7	Digital Pin 4
8	Digital Pin 5 (PWM)
9	Digital Pin 6 (PWM)
10	Digital Pin 7
11	Digital Pin 8
12	Digital Pin 9 (PWM)
13	Digital Pin 10 (PWM-SS)
14	Digital Pin 11 (PWM-MOSI)
15	Digital Pin 12 (MISO)
16	Digital Pin 13 (SCK)
18	AREF
19	Analog Input 0
20	Analog Input 1
21	Analog Input 2
22	Analog Input 3
23	Analog Input 4
24	Analog Input 5
25	Analog Input 6
26	Analog Input 7
27	VCC
30	Vin

The current reader circuit is designed to read the current generated by the solar panel, where the circuit consists of an Arduino Nano, a current reader sensor, an LCD, and a Project Board. Each electronic component used in this system has a specific pin configuration that

functions as a communication path and power supply. Arduino Nano, as the main microcontroller, is equipped with digital pins, analog pins, serial communication pins, and power supply pins that can be used to connect various external modules, the pin configuration can be seen in Table 6.

The ACS712 current sensor also has a simple pin configuration consisting of power supply pins (VCC and GND) and an analog output pin that produces a voltage proportional to the measured current, while the current input lines (+ and -) are used to supply electrical loads as seen in Table 7.

**Table 7.** Current Sensor Pin Configuration (ACS712)

PIN Number	Pin Name	Function
1	VCC	+5 V supply voltage
2	GND	Ground
3	OUT	Analog output (voltage proportional to current)
-	IP+	Current input (+) - main load line
-	IP-	Current input (-) - main load line

Meanwhile, the 16x2 LCD module with the HD44780 driver has a more complex pin configuration, including power supply pins (VSS, VDD), contrast adjustment pins (V0), control pins (RS, R/W, E), and data pins (D0-D7) that can be used in 4-bit or 8-bit mode. In addition, there are also special pins to activate the backlight (LED+ and LED-) which can be seen in Table 7.

**Table 8.** 16 x 2 LCD Pin Configuration

PIN Number	Pin Name	Function
1	VSS	Ground
2	VDD	+5 V
3	V0	Display contrast (via potentiometer)
4	RS	Register Select (0 = instruction, 1 = data)
5	R/W	Read/Write (0 = Write, 1 = Read)
6	E	Enable
7-14	D0-D7	Data bus (8 bits, can be used in 4-bit mode with D4-D7 only)
15	LED+	Anode backlight (LED)
16	LED-	Cathode backlight (LED)

By understanding the pin configuration of each component, the circuit design and programming process becomes more systematic and minimizes errors in installation and system operation.

The inverter is designed to convert DC current into AC current, where the inverter circuit consists of various transistors, resistors, capacitors, diodes, and transformers. The tool frame is designed to be sturdy to withstand the load of solar panels and evaporation tanks. With this design, the tool is able to independently

produce fresh water suitable for consumption from seawater, with the main energy sourced from the sun. Its main advantages are energy efficiency, ease of maintenance, low cost, and environmental friendliness. This product is not only beneficial for coastal communities in meeting clean water needs, but can also be used as a contextual learning medium that integrates the concepts of renewable energy, the water cycle, and simple technological engineering.

*Product Manufacturing Stage*

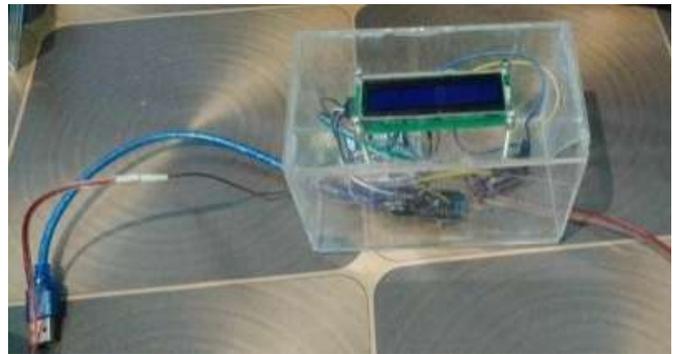
In the product development stage, there are three main stages, namely: The first stage is the creation of the evaporation tank. This process begins with cutting acrylic sheets, then gluing them together using special adhesive to form a box that functions as a water container. On one side of the box, a hole is made for the heater. After that, another acrylic sheet is cut and arranged to resemble a roof to cover the water container, then neatly glued. On each side of the roof, a water flow path is formed using foam soles so that the water can flow in a directed manner. From the four corners of the roof, hoses are installed to channel the collected water to the next collection container (as seen in Figure 3).



**Figure 3.** Evaporation tank of the solar panel seawater purifier

The second stage is the assembly of the current reader circuit. First, the acrylic is cut again to form a box for housing the electronic components. The Arduino board and current reader sensor (ACS758) are prepared, then the connections are made: the Arduino 5V pin is connected to the VCC pin of the sensor and LCD, while the Arduino GND pin is connected to the GND pin of the sensor and LCD. The Out1 pin on the sensor is connected to the A0 pin of the Arduino, while the SDA and SCL pins on the LCD are connected to the A4 and A5 pins of the Arduino. After all the connections are completed, the Arduino is programmed to read the current from the solar panel and display the measurement results on the LCD. The finished circuit is then placed in the previously prepared acrylic box and

securely fixed to ensure proper protection, as can be seen in Figure 4.



**Figure 4.** Current reader circuit for seawater purifier with solar panel

The third stage is the inverter assembly. First, six K3057 MOSFET transistors, a TL494 IC, six 100-ohm resistors, two 220-ohm resistors, one 2.2 kΩ resistor, one 22 kΩ resistor, one 10 kΩ resistor, a 1 μF 63 V capacitor, a 470 μF 25 V capacitor, several 4007 diodes, and a PCB and transformer are prepared. The process begins by connecting the gate of each transistor through a 100-ohm resistor, then the source is connected in parallel, as is the drain. Two 220-ohm resistors are installed between the source and gate of two specific transistors. The TL494 IC circuit is then connected with various resistors, capacitors, and inter-pin connections according to the PWM control function. Next, a 470 μF capacitor and diodes are installed to support input stability, then the positive and negative input cables are prepared with alligator clips so they can be connected to the battery. The output of the IC is connected to the gate of the transistor, while the source of the transistor is connected to the negative input line of the IC. The transformer is installed with a 12 V line connected to the drain of the transistor, while the CT (center tap) is connected to the positive input of the IC. Finally, the 0 V and 220 V output cables from the transformer are connected to the power plug so that the inverter is ready to be used to generate AC current from the DC source of the battery, as seen in Figure 5.



**Figure 5.** Solar panel seawater purifier inverter circuit

After the evaporation tank, Arduino circuit assembly, and inverter assembly have been completed, the process continues by integrating all components so that the system can function as a whole. The positive output cable from the solar panel is connected to the positive input of the ACS758 sensor on the Arduino circuit, while the negative input of the sensor is connected to the positive input of the SCC on the solar panel. The negative output of the solar panel is connected to the negative input of the SCC, then the Arduino ground is connected to the negative output cable of the panel. Next, the battery is connected to the SCC via a dedicated battery pin, and the Arduino circuit is powered using a 5 V adapter. The inverter is then connected to the battery, and the heating element cable is plugged into the dimmer that has been connected to the inverter, as seen in Figure 6.



Figure 6. Solar panel seawater purifier

The main components of this solar-powered seawater purifier include a solar panel, a current sensor circuit, a solar charge controller, a power storage battery, an inverter, a DC dimmer, an evaporation tank, a clear pipe, and a freshwater reservoir. The solar panel captures solar energy, which is then stored in the battery. This energy is then channeled through the inverter to power the heating element.

The seawater purification process begins with seawater being poured into a seawater reservoir for evaporation. Inside the evaporation tank, the water is

heated by two energy sources. First, direct solar heat helps raise the water temperature. Second, additional heat is obtained from an electric heating element. This heating element is powered by a solar panel system installed to absorb solar energy. The solar panel converts solar energy into electrical energy. The resulting electrical current is measured by a current sensor circuit, while the voltage is monitored by a solar charge controller. The collected electricity is then stored in a battery for continuous use. From the battery, the current flows to an inverter, which converts direct current (DC) to alternating current (AC) to power the heating element.

The heat from the heating element causes the seawater in the evaporation tank to evaporate. The salt and impurities in the seawater remain at the bottom of the tank, while the resulting water vapor is directed through a pipe to a freshwater reservoir. In this reservoir, the vapor condenses, turning into clean, usable water.

*Analysis of Empirical Test Results Data*

Empirical testing of freshwater quality values was obtained by comparing water consumption standards with the results of the developed tool. According to the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023 concerning Drinking Water Quality Requirements, Article 1 states that drinking water is water that has undergone a processing process or no processing process that meets health requirements and can be consumed directly. Clean water is water used for daily needs whose quality meets health requirements and can be consumed after being boiled (Kementerian Kesehatan, 2023).

Clean water quality requirements include physical, chemical, and bacteriological requirements. Physically, clean water must be clear, odorless, and tasteless, while chemically, it must be free of toxic substances that could harm health. This test essentially measures the precision and accuracy of the measurement results from the developed device in meeting water consumption standards. Measurements using the seawater purifier are shown in Table 9.

Table 9. Empirical Data on Fresh Water Produced

Time	Sunlight intensity (Cd)	Ambient humidity (%)	Ambient Temperature (°C)	Time (Seconds)	Current (A) solar panel to battery	Voltage (V) of solar panel to battery	Input Power (Watts)	Energy (Joule)	Volume of fresh water produced (ml)
08.00	885000	33	25	1800	2.4	13	31.2	56160	0
08.30	250000	27	25	3600	1.35	11.1	14.99	53946	0
09.00	886000	25	26	5400	2.14	12.3	26.32	142138.8	7
09.30	1034000	21	26	7200	3.95	12.8	50.56	364032	13
10.00	1058000	20	28	9000	5.03	12.9	64.89	583983	25
10.30	1275000	19	28	10800	6.37	12.2	77.71	839311.2	37
11.00	1059000	18	29	12600	5.09	12.9	65.66	827328.6	48

Time	Sunlight intensity (Cd)	Ambient humidity (%)	Ambient Temperature (°C)	Time (Seconds)	Current (A) solar panel to battery	Voltage (V) of solar panel to battery	Input Power (Watts)	Energy (Joule)	Volume of fresh water produced (ml)
11.30	1050000	20	29	14400	5.03	11.4	57.34	825724.8	54
12.00	1025000	22	31	16200	3.05	10.5	32.03	518805	57
12.30	885000	25	31	18000	2.48	10.6	26.29	473184	61
13.00	1025000	23	32	19800	3.03	10.06	1.275	25247.48	63
13.30	889000	24	32	21600	2.82	10.6	29.89	645667.2	65
14.00	789000	23	31	32400	2.35	10.6	24.91	807084	68
14.30	573000	29	31	25200	2.33	10.5	24.47	616518	69
15.00	205000	35	31	27000	2.07	10.4	21.53	581256	70
15.30	3100	40	31	28800	0.41	10.4	4.264	122803.2	73

A comparison of the quality of seawater used for the experiment and freshwater produced after using a seawater purifier with water consumption standards as stipulated in (Kementerian Kesehatan, 2023) can be seen in Table 10.

The results demonstrated consistent performance, with the device still producing good-quality fresh water despite varying production volumes depending on sunlight intensity. While cloudy conditions did reduce production, the purified water remained potable. This demonstrates the system's resilience to climate variability in coastal areas.

Sunlight intensity plays a significant role in the success of the distillation process. Between 1:00 PM and 1:30 PM, with a light intensity of 889,000-1,025,000 lux and an air temperature of 32°C, water production reaches its optimal level. This demonstrates that the timing of operations and the location of the equipment are crucial for success. The use of solar panels as an energy source also emphasizes the importance of harnessing the abundant natural energy potential in tropical regions like Indonesia.

**Table 10.** Quality Data of Seawater Used and Freshwater Produced

Parameter	Sea Water (Test)	Fresh Water (Purified Result)	Drinking Water Consumption Standards
pH	6.86	6.83	6.5 – 8.5
TDS	1364 ppm	124 ppm	50 – 300 ppm
Salinity	0.88%	0.01%	< 0.5 %
Temperature	40.4 °C	31.4 °C	10 – 25 °C
Specific Gravity (SG)	1	1	≤ 2.5
ORP	1999 mV	224 mV	200 – 600 mV
EC	1778 µS/cm	0 µS/cm	≤ 2000 µS/cm (≈ 200 mS/m)
Water Color	Colored	Colorless	Colorless
Smell	Odorless	Odorless	Odorless

Water quality tests showed a pH of 6.83, TDS of 124 ppm, in accordance with WHO standards (TDS < 500 ppm), Salinity of 0.01%, Specific Gravity (SG) of 1.00, ORP of 224 mV, and EC of 0 µS/cm. This means that even though the production volume varies between models, water quality remains maintained. This quality reliability is crucial in ensuring widespread use of this technology in coastal communities (Ernidawati et al., 2021).

*Validation Results of Seawater Purifier Device*

The designed seawater purifier was tested and its functionality was measured using a validation instrument. The tool was validated by experts to ensure it was error-free and suitable for use as a learning tool. Validation was conducted by three experts with doctoral degrees in educational sciences. The validation results from the three validators are shown in Table 11.

**Table 11.** Validation Results of Solar Panel Seawater Purifier

Validator	Tool Functionality	Learning Elements	Convenience	Aesthetics and Construction	Job Security	Average
1	3.5	3.5	3.5	3.67	3.5	3.534
2	3.75	3.83	4	4	4	3.916
3	3.5	4	3.5	3.67	4	3.734
Average	3.58	3.77	3.67	3.78	3.83	3.728

Based on the validation results conducted by three validators on the solar panel-based seawater purifier

learning media, the results showed that each assessment aspect demonstrated a high to very high level of validity.

In terms of tool functionality, the assessment results were in the high category. This media was deemed capable of producing fresh water from seawater through a solar distillation process, the solar panels used were able to absorb solar energy effectively, and the tool could demonstrate the conversion of solar energy into heat energy effectively. In addition, the tool had good precision in reading measurement results. These results indicate that the tool has functioned according to its development objectives, although it still needs improvement in the efficiency of the distillation process to produce clearer water and in the positioning of the solar panels for maximum energy absorption.

In terms of learning elements, the validation results showed a very high rating. This learning media can apply renewable energy concepts, is effective for use in high school physics lessons, integrates physics phenomena with everyday life, and trains students' scientific thinking skills. This demonstrates that the tool significantly supports physics learning activities because it connects theory with practice, while simultaneously fostering students' critical and analytical thinking skills through experiments and direct observation.

The ease-of-use aspect received a high rating. This learning tool was deemed easy to prepare before use, easy to operate, and easy to transport from one location to another. These results indicate that the tool is relatively practical for both teachers and students, although improvements are needed in the assembly guide and component labeling to make use and storage more efficient.

The aesthetic and construction aspects are classified as very high. The learning media has an attractive shape, with a well-organized and neat structure. These results

indicate that the tool has an appealing and well-proportioned appearance, giving a professional impression when used. However, improvements are still needed in the finishing and component arrangement to enhance the visual appeal and structural sturdiness of the tool for greater durability during repeated use in learning activities.

The safety aspect is also rated very high. The learning media is considered safe for use in physics learning activities, both in the classroom, in the laboratory, and in the field. The solar panel components and heating system have been installed properly and pose minimal risk to users. However, the validator recommends adding protective shields to hot areas and ensuring that all cables and electrical connections are properly protected to enhance safety during use.

Overall, the validation results indicate that the solar panel-based seawater purifier learning media has a very high level of validity and is highly suitable for use in physics lessons. This media not only supports students' understanding of renewable energy concepts and energy conversion processes, but also serves as an innovative tool for fostering scientific thinking skills and awareness of environmentally friendly energy use in coastal areas.

*Practical Results of Solar Panel Seawater Purifier*

The practicality of this seawater purifier was also measured using a questionnaire. The practicality test was conducted to determine the device's ease of use, attractiveness, and usefulness as a learning tool. This practicality instrument was administered to 29 students and two teachers directly involved in the trial. The results of the teacher practicality test are shown in Table 12.

**Table 12.** Practical Results of Teachers' Solar Panel Seawater Purifier

Teacher	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Average
1	4	3	4	4	4	4	4	3.86
2	4	3	4	4	4	4	4	3.86
Average	4.00	3.00	4.00	4.00	4.00	4.00	4.00	3.86
Practicality	Very							
Category	Practical							

Based on the practicality assessment conducted by teachers, the first item indicates that the solar panel-based seawater purifier learning media is easy to use and understand, with a rating of very practical. This indicates that the solar panel seawater purifier is easy to operate and comprehend for teachers. The instructions are clear, the device design is simple, and its components are easily recognizable, allowing teachers to use it without requiring special training. This ease of use supports the effectiveness of learning activities both in the classroom and outdoors.

The second item regarding the time required to operate the device qualifies as practical. This means that the time required to set up, operate, and complete the experiment is still within the allocated classroom learning time. However, minor adjustments to improve time efficiency, such as simplifying the heating or seawater filling steps, could be made to optimize the device's use within a single class hour.

In the third item, the assessment results indicated a very practical category, meaning that the solar panel-based seawater purifier learning tool is safe to use and

poses no danger to students. The tool is considered safe because it contains no hazardous chemicals, and all electrical components are well protected. The heating system and solar panel are also low-power, so they pose no risk of fire or electric shock. This high level of safety makes the tool suitable for student use in practical activities.

The fourth item shows that the solar panel-based seawater purifier learning media helped improve students' understanding of the desalination process and solar energy utilization, with a very practical rating. Teachers assessed this tool as effective in explaining physics concepts such as solar energy conversion into heat energy and the seawater desalination process. Through direct observation, students were able to understand how renewable energy is used to produce fresh water.

Furthermore, the fifth item shows that the solar panel-based seawater purifier learning tool can increase students' motivation in learning physics, categorized as very practical. Experimental activities using this tool foster students' curiosity about the application of physics in real-life contexts. Learning becomes more engaging because students can participate actively, thereby increasing their enthusiasm for learning.

In the sixth item, the assessment results also indicated a very practical category, namely that the solar panel-based seawater purifier learning media helped students develop practical skills and critical thinking abilities. Teachers assessed that practical activities using this tool encouraged students to make observations, analyze data, and draw scientific conclusions. Thus, this tool contributed to improving students' critical thinking skills and scientific competence.

The seventh item indicates that students gained real-world experience in learning about energy sources, categorized as very practical. Through the use of this tool, students gained firsthand experience in utilizing solar energy as a renewable energy source. This experience made learning more contextual and meaningful, as students could see the real application of energy concepts in everyday life.

Based on the results of the student practicality assessment, the overall findings are consistent with the teachers' assessment results for each instrument item. For the first item, students gave an average score of 3.45, indicating that the solar panel-based seawater purifier is easy to use and understand. Students assessed the device's simple design, easily recognizable components, and clear instructions. This allowed them to operate the device without intensive guidance, resulting in an effective and enjoyable practicum.

The second item received an average score of 3.00, which falls into the practical category. This score indicates that the time required to set up and operate the

equipment is still relatively efficient, but students felt that certain steps—such as seawater filling or heating—needed to be simplified so that the practical activity could be completed more efficiently within one class hour.

The third item received an average score of 3.62, categorized as very practical. Students considered the tool safe to use because all electrical components were well protected and did not pose hazards such as electric shock or overheating. This high level of safety provided students with a sense of comfort during the experiment.

The fourth item received an average score of 3.66, categorized as very practical. Students found this tool highly helpful in understanding the concepts of desalination and solar energy conversion into heat. Through direct observation of the seawater purification process, students were able to connect physics theory with real-life applications.

The fifth item received an average score of 3.72, categorized as very practical. These results indicate that the use of a solar panel-based seawater purifier can increase students' learning motivation. The experimental activities stimulated their curiosity and enthusiasm in learning about the application of renewable energy in physics.

The sixth item received an average score of 3.76, one of the highest scores in the student assessment. This item indicates that the tool was highly effective in helping students develop practical skills, data analysis abilities, and critical thinking during the experiment. Students were encouraged to observe, record data, and draw scientific conclusions independently.

The seventh item also received an average score of 3.76, equal to the sixth item. This score indicates that students gained a meaningful real-world learning experience in understanding the concept of energy sources. Through practical activities, they were able to observe firsthand how solar energy is used to produce fresh water from seawater, making learning more contextual and applicable.

The primary social benefit of the design, assembly, and testing process is that students understand how simple technology can address real-world problems in their environment. This provides firsthand experience that technology can be continuously developed and improved within local contexts, and that its application is highly practical. The resulting fresh water can be used for daily needs, including drinking, cooking, and basic hygiene. The availability of clean water encourages the independence of coastal communities in meeting their needs without relying on external supplies, which are often expensive and limited. This simple technology can also be operated independently, thereby increasing community empowerment (Madhuri et al., 2025).

The resulting environmental impact is positive because this system utilizes solar energy entirely. It eliminates dependence on fossil-based energy sources, thereby reducing carbon emissions (Alsakkaf et al., 2022). The implementation of this technology aligns with global efforts to transition to environmentally friendly energy sources. Its application in coastal areas is not only a technical solution but also a strategic step in supporting the sustainable development agenda (Widjonarko et al., 2023).

From an economic perspective, this device is more cost-effective than conventional desalination technologies such as reverse osmosis (Hamdan et al., 2021). The materials used are readily available locally, simplifying maintenance and spare part replacement (Kaya et al., 2019). This cost-effectiveness makes the device more feasible for implementation in low-income communities. This solution presents a realistic, affordable, and sustainable innovation (Saeed AL-Ghamdi et al., 2022).

Research by Natawisastro et al. (2022) demonstrated the effectiveness of adding a simple heater to a solar water distiller in increasing the evaporation rate by more than 300% under optimal conditions. The results of this study are consistent with those findings, where increasing the number of heating elements significantly increased freshwater production volume. This similarity strengthens the scientific basis that simple modifications can improve the efficiency of solar-based technologies.

Research by Iswadi (2016) on a water pyramid system with a greenhouse effect demonstrated that utilizing pure solar energy can produce potable water that meets health standards. Their design demonstrated that simple distillation principles can address clean water needs in coastal areas. This research is relevant because it emphasizes the importance of a simple, locally-based approach.

Study of Sugawara et al. (2014) developed a water and salt separator utilizing solar panels, producing fresh water and salt as a byproduct. This research confirms that seawater purification not only provides benefits for basic needs but also opens economic opportunities for coastal communities. Integrating this research with the innovation of solar panel-based water purifiers illustrates the potential for product diversification.

Research by Gaib et al. (2023) also demonstrated the effectiveness of solar-powered seawater distillation in producing good-quality freshwater, despite relatively limited production volumes. Their results underscore the importance of a design tailored to local conditions to maximize production. The relevance of this research reinforces that simple solar-powered solutions remain a viable solution to the clean water crisis.

The development of solar panel-based seawater purification technology faces technical challenges, one of which is decreased panel efficiency due to high temperatures. Research by Kalandro et al. (2025) on solar panel cooling systems showed an efficiency increase of up to 3% by setting the panel temperature between 33–36 °C. Integrating cooling systems with water purification technology has the potential to increase productivity and device stability in the future.

## Conclusion

Based on the research results, the solar panel-based seawater purifier that has been designed, validated, and tested shows good performance and is suitable for use as a learning medium. The validation results from three experts with doctoral qualifications in science education yielded an average score of 3.728, categorized as very valid, indicating that the tool meets the aspects of functionality, learning elements, ease of use, aesthetics, construction, and operational safety. The practicality test involving 29 students and two teachers resulted in an average score of 3.60 from students and 3.86 from teachers, both categorized as very practical. This indicates that the tool is easy to use, attractive, and effective in supporting physics learning, particularly in renewable energy topics. In addition, field test results showed that the tool is capable of producing fresh water of good quality in accordance with WHO standards, although production volume is influenced by sunlight intensity and heating element configuration. Therefore, this solar panel-based seawater purifier is declared valid, practical, and highly potential for use both as a learning medium and as a solution to clean water needs in coastal communities.

## Acknowledgments

The authors would like to thank the Institute for Research and Community Service, University of Riau, for funding the 2025 Product and Prototype Research Scheme, and the Head and all staff of the Institute for Research and Community Service, University of Riau. We hope this research will benefit the advancement of education in Indonesia.

## Author contributions

All author in this research has significant roles.

## Funding

The Institute for Research and Community Service, University of Riau, for funding the 2025 Product and Prototype Research Scheme.

## Conflicts of Interest

All author declare that there is no conflict of interest.

## References

- Alaswad, S. O., Mansor, E. S., Abdallah, H., & Shaban, A. M. (2025). Modification of blend reverse osmosis membranes using ZrO<sub>2</sub> for desalination process purposes. *Applied Water Science*, 15(1), 1–12. <https://doi.org/10.1007/s13201-024-02329-6>
- Alrowais, R., Shahzad, M. W., Burhan, M., Bashir, M. T., Chen, Q., Xu, B. Bin, Kumja, M., Markides, C. N., & Ng, K. C. (2022). A thermally-driven seawater desalination system: Proof of concept and vision for future sustainability. *Case Studies in Thermal Engineering*, 35(May), 102084. <https://doi.org/10.1016/j.csite.2022.102084>
- Alsakkaf, Z. A., Al-Dahbali, G. A. A., & Saeed, A. A. M. (2022). Study of a New Passive Solar Desalination Design With a Heat Recycling System. *Electronic Journal of University of Aden for Basic and Applied Sciences*, 3(3), 214–221. <https://doi.org/10.47372/ejua-ba.2022.3.188>
- Bekliu, N., Marlensi Maubana, W., Lipikuni, H. F., & Boimau, Y. (2025). Analisis Kualitas Air Tanah Berdasarkan Parameter Fisika dan Kimia di Sekitar Pantai Lai-Lai Bisi Kopan (LLBK) Kota Kupang. *Magnetic: Research Journal Of Physics and It's Application*, 5(2), 2775–8583. <https://doi.org/10.59632/magnetic.v5i2.485>
- Chebil, S., Ruiz-García, A., Farhat, S., & Bali, M. (2024). Long-Term Performance Evaluation and Fouling Characterization of a Full-Scale Brackish Water Reverse Osmosis Desalination Plant. *Water (Switzerland)*, 16(13). <https://doi.org/10.3390/w16131892>
- Curto, D., Franzitta, V., & Guercio, A. (2021). A review of the water desalination technologies. *Applied Sciences (Switzerland)*, 11(2), 1–36. <https://doi.org/10.3390/app11020670>
- Dimitriou, E., Camacho-Espino, J., Anastasiou, A., & Papadakis, G. (2025). Experimental investigation of the performance of a seawater reverse osmosis desalination system operating under variable feed flowrate pressure and temperature conditions. *Journal of Environmental Chemical Engineering*, 13(2), 115778. <https://doi.org/10.1016/j.jece.2025.115778>
- Doornbusch, G. J., Tedesco, M., Post, J. W., Borneman, Z., & Nijmeijer, K. (2019). Experimental investigation of multistage electrodialysis for seawater desalination. *Desalination*, 464(February), 105–114. <https://doi.org/10.1016/j.desal.2019.04.025>
- Ernidawati, E., Sahal, M., Fauza, N., Syaflita, D., & Satria, D. (2021). Pengembangan Alat Pemurni Air Laut sebagai Media Pembelajaran Fisika SMA pada Materi Pemanasan Global. *Journal of Natural Science and Integration*, 4(2), 222. <https://doi.org/10.24014/jnsi.v4i2.14529>
- Gaib, D., Arbie, A., & Setiawan, D. G. E. (2023). Rancang Bangun Alat Destilasi Air Laut Menggunakan Tenaga Matahari Sebagai Alternatif Penyediaan Air Bersih. *Jurnal Fisika: Fisika Sains Dan Aplikasinya*, 8(1), 37–43. <https://doi.org/10.35508/fisa.v8i1.11822>
- Goosen, M., Mahmoudi, H., Alyousef, Y., & Ghaffour, N. (2023). Solar desalination: A review of recent developments in environmental, regulatory and economic issues. *Solar Compass*, 5(February). <https://doi.org/10.1016/j.solcom.2023.100034>
- Hadi, S., Permadi, A., Maryudi, Syamsuddin, A., & Fatwa Zufar, A. (2024). Analysis water content of Seawater Desalination Technology by Using Multistage Distillation. *Indonesian Journal of Chemical Engineering*, 2(1), 22–28. <https://doi.org/10.26555/ijce.v2i1.675>
- Hamdan, H., Saïdy, M., Alameddine, I., & Al-Hindi, M. (2021). The feasibility of solar-powered small-scale brackish water desalination units in a coastal aquifer prone to saltwater intrusion: A comparison between electrodialysis reversal and reverse osmosis. *Journal of Environmental Management*, 290. <https://doi.org/10.1016/j.jenvman.2021.112604>
- Ibrahim, M. M. (2022). Technical and Economic Comparison between Solar and Wind Energy Supplying Desalination System. *Journal of Sustainable Development of Energy, Water and Environment Systems*, 10(2). <https://doi.org/10.13044/j.sdewes.d8.0382>
- Idrees, H., Ali, S., Sajid, M., Rashid, M., Khawaja, F. I., Ali, Z., & Anwar, M. N. (2023). Techno-Economic Analysis of Vacuum Membrane Distillation for Seawater Desalination. *Membranes*, 13(3). <https://doi.org/10.3390/membranes13030339>
- Iswadi, M. S. L. (2016). Rancang bangun alat pemurni air laut menjadi air minum menggunakan sistem piramida air. *Jurnal Sains Dan Pendidikan Fisika*, 12(3), 300–310. <https://doi.org/10.35580/jspf.v12i3.3057>
- Kaya, A., Evren Tok, M., & Koc, M. (2019). A leveled cost analysis for solar-energy-powered sea water desalination in the Emirate of Abu Dhabi. *Sustainability (Switzerland)*, 11(6). <https://doi.org/10.3390/su11061691>
- Kementerian Kesehatan. (2023). *Permenkes No. 2 Tahun 2023*. Kemenkes Republik Indonesia.
- Madhuri, R. V. S., Said, Z., Ihsanullah, I., & Sathyamurthy, R. (2025). Solar energy-driven desalination: A renewable solution for climate change mitigation and advancing sustainable development goals. *Desalination*, 602. <https://doi.org/10.1016/j.desal.2025.118575>

- Madupathi, M. M., Srishti, S., Fatima, S., & Sridhar, S. (2024). Sea and brackish water desalination through a novel PVDF-PTFE composite hydrophobic membrane by vacuum membrane distillation. *Discover Chemical Engineering*, 4(1). <https://doi.org/10.1007/s43938-024-00044-x>
- Marx, O. P., & Gasser, I. (2025). *Modelling, simulation and optimisation of seawater reverse osmosis - pressure-retarded osmosis ( SWRO - PRO ) hybrid units for seawater desalination* (Vol. 123). Springer Netherlands.
- McPeake, K., North, C., Townend, E., Dixon, K., Jeanes, L., Cooke, S., Kane, R., Selby, P., Lawler, M., & Nelson, D. (2025). Ensuring equitable and affordable access to clean water for people living with cancer in a rural and coastal setting. *Journal of Cancer Policy*, 44. <https://doi.org/10.1016/j.jcpo.2025.100572>
- Mulyatiningsih, E. (2016). *Pengembangan model pembelajaran*. Retrieved from <https://shorturl.at/uEl2o>
- Nabil, I., Dawood, M. M. K., Mansour, T. M., Shehata, A. I., & Abdalla, A. M. (2025). Improved productivity of seawater desalination systems through humidification-dehumidification process integrated with renewable and fogging technologies in a lowest cost. *Applied Water Science*, 15(6), 1-25. <https://doi.org/10.1007/s13201-025-02446-w>
- Natawisastra, R., Bramawanto, R., Ma'muri, M., Alfaris, L., & Suhernalis, S. (2022). Rancang Bangun Alat Destilasi Air Laut yang Dilengkapi Pemanas Air Sederhana. *Jurnal Kelautan Nasional*, 17(2), 161. <https://doi.org/10.15578/jkn.v17i2.11382>
- Nisa, A., Wijaya, I., & Sefriani, R. (2023). Uji Praktikalitas E-Modul Pembelajaran Project Based Learning Menggunakan Sigil Pada Mata Pelajaran Dasar-Dasar Kejuruan Siswa Kelas X Pengembangan Perangkat Lunak dan GIM (PPLG) di SMK N 1 Singkarak. *PIJAR: Jurnal Pendidikan Dan Pengajaran*, 2(1), 12-20. <https://doi.org/10.58540/pijar.v2i1.427>
- Pan, Y., Li, E., Wang, Y., Liu, C., Shen, C., & Liu, X. (2022). Simple Design of a Porous Solar Evaporator for Salt-Free Desalination and Rapid Evaporation. *Environmental Science and Technology*, 56(16), 11818-11826. <https://doi.org/10.1021/acs.est.2c03240>
- Philibert, M., Villacorte, L. O., Ekowati, Y., Abushaban, A., & Salinas-Rodriguez, S. G. (2024). Fouling and scaling in reverse osmosis desalination plants: A critical review of membrane autopsies, feedwater quality guidelines and assessment methods. *Desalination*, 592(October), 118188. <https://doi.org/10.1016/j.desal.2024.118188>
- Prasetyo, N. A., & Perwiraningtyas, P. (2017). Pengembangan Buku Ajar Berbasis Lingkungan Hidup pada Matakuliah Biologi di Universitas Tribhuwana Tunggaladewi. *Jurnal Pendidikan Biologi Indonesia*, 3(1), 19-27. Retrieved from <http://ejournal.umm.ac.id/index.php/jpbi>
- Purwanto, M., Kusuma, N. C., Sudrajat, M. A., Jaafar, J., Nasir, A. M., Aziz, M. H. A., Othman, M. H. D., Rahman, M. A., Raharjo, Y., & Widiastuti, N. (2021). Seawater desalination by modified membrane distillation: Effect of hydrophilic surface modifying macromolecules addition into pvdf hollow fiber membrane. *Membranes*, 11(12). <https://doi.org/10.3390/membranes11120924>
- Rahmani, S., Murayama, T., & Nishikizawa, S. (2022). Socio-economic Impact of a Solar Water Pumping System in a Rural Community in Indonesia. *Journal of Sustainable Development of Energy, Water and Environment Systems*, 10(3). <https://doi.org/10.13044/j.sdewes.d9.0403>
- Rezaei, L., Dehghani, M., Hassani, A. H., & Alipour, V. (2020). Seawater reverse osmosis membrane fouling causes in a full scale desalination plant; through the analysis of environmental issues: Raw water quality. *Environmental Health Engineering and Management*, 7(2), 119-126. <https://doi.org/10.34172/EHEM.2020.14>
- Saeed AL-Ghamdi, A., Mohammed Mahmoud, A., & Bamardouf, K. (2022). Solar Desalination Methods and Economics (Literature Review). *American Journal of Energy Engineering*, 10(4), 92-102. <https://doi.org/10.11648/j.ajee.20221004.12>
- Sembiring, E. T. J., & Safithri, A. (2023). Permasalahan Sanitasi di Pemukiman Pesisir Jakarta serta Rekomendasi Teknologi Pengelolaannya. *Environmental Occupational Health and Safety Journal*, 3(2), 199. <https://doi.org/10.24853/eohjs.3.2.199-214>
- Shatat, M., & Riffat, S. B. (2014). Water desalination technologies utilizing conventional and renewable energy sources. *International Journal of Low-Carbon Technologies*, 9(1), 1-19. <https://doi.org/10.1093/ijlct/cts025>
- Shouman, L. A., Afify, R. M., Fadel, D. A., & Esawy, M. H. (2024). Fouling effect on Reverse Osmosis (RO) membranes performance in desalination plant. *Desalination and Water Treatment*, 319(June), 100502. <https://doi.org/10.1016/j.dwt.2024.100502>
- Sikder, S., Toha, M., Rahman, M. M., & Sikder, M. H. (2024). Efficiency of microbial desalination cells in treating wastewater, desalinating saltwater, and generating bioelectricity in Bangladesh. *RSC Advances*, 14(52), 38547-38559. <https://doi.org/10.1039/d4ra06317a>
- Sugawara, E., & Nikaido, H. (2014). Properties of AdeABC and AdeIJK efflux systems of

- Acinetobacter baumannii compared with those of the AcrAB-TolC system of Escherichia coli. *Antimicrobial Agents and Chemotherapy*, 58(12), 7250-7257. <https://doi.org/10.1128/AAC.03728-14>
- Wibowo, A. I., & Chang, K. C. (2020). Solar energy-based water treatment system applicable to the remote areas: Case of indonesia arsanto ishadi wibowo and keh-chin chang. *Journal of Water Sanitation and Hygiene for Development*, 10(2), 347-356. <https://doi.org/10.2166/washdev.2020.003>
- Widjonarko, W., Aditya Rahardi, G., Rudiyanto, B., Ishamul Ayady Akma, A., & Ahmed Mohammed Ate, A. (2023). Solar-powered seawater desalination: A contribution to provide energy-efficient clean water. *Borobudur Engineering Review*, 3(1), 25-38. <https://doi.org/10.31603/benr.9042>
- Wigati, R., Kulsum, K., & Bethary, R. T. (2018). Pemberdayaan Kawasan Pesisir Utara Banten Melalui Kelompok Usaha Bersama Berbasis Kearifan Lokal. *Jurnal Pengabdian Dinamika*, 1-9. Retrieved from <http://jurnal.untirta.ac.id/index.php/Dinamika/article/view/8744>
- Wu, S. L., Chen, H., Wang, H. L., Chen, X., Yang, H. C., & Darling, S. B. (2021). Solar-driven evaporators for water treatment: Challenges and opportunities. *Environmental Science: Water Research and Technology*, 7(1), 24-39. <https://doi.org/10.1039/d0ew00725k>
- Yoshi, L. A., & Widiassa, I. N. (2017). Studi Tekno Ekonomi Desalinasi Air Laut Skala Kecil Dengan Sistem Reverse Osmosis. *Reaktor*, 16(4), 218. <https://doi.org/10.14710/reaktor.16.4.218-225>
- Yosry, N., Elgendy, E., Mostafa, A., & Fatouh, M. (2024). Hybrid air conditioning and seawater desalination system assisted by solar energy: thermoeconomic investigation and optimization. *Journal of Engineering and Applied Science*, 71(1), 1-19. <https://doi.org/10.1186/s44147-024-00480-0>