2025 Climate Change Innovation Competition

[Final Work]

Team No	01
Team Name	**Upcycle Champions** 極淨創能者
Work Name	**Ashes to Innovation: Upcycling Coal Ash into cutting-edge 3D-printed Ceramic Membranes for water reclamation and energy generation.** 新一代煤灰製備 **3D** 列印陶瓷膜

School: National Taipei University of Technology

Department: Institute of Environmental Engineering and Management

Advisor: Lifetime Distinguished Prof. Shiao Shing Chen

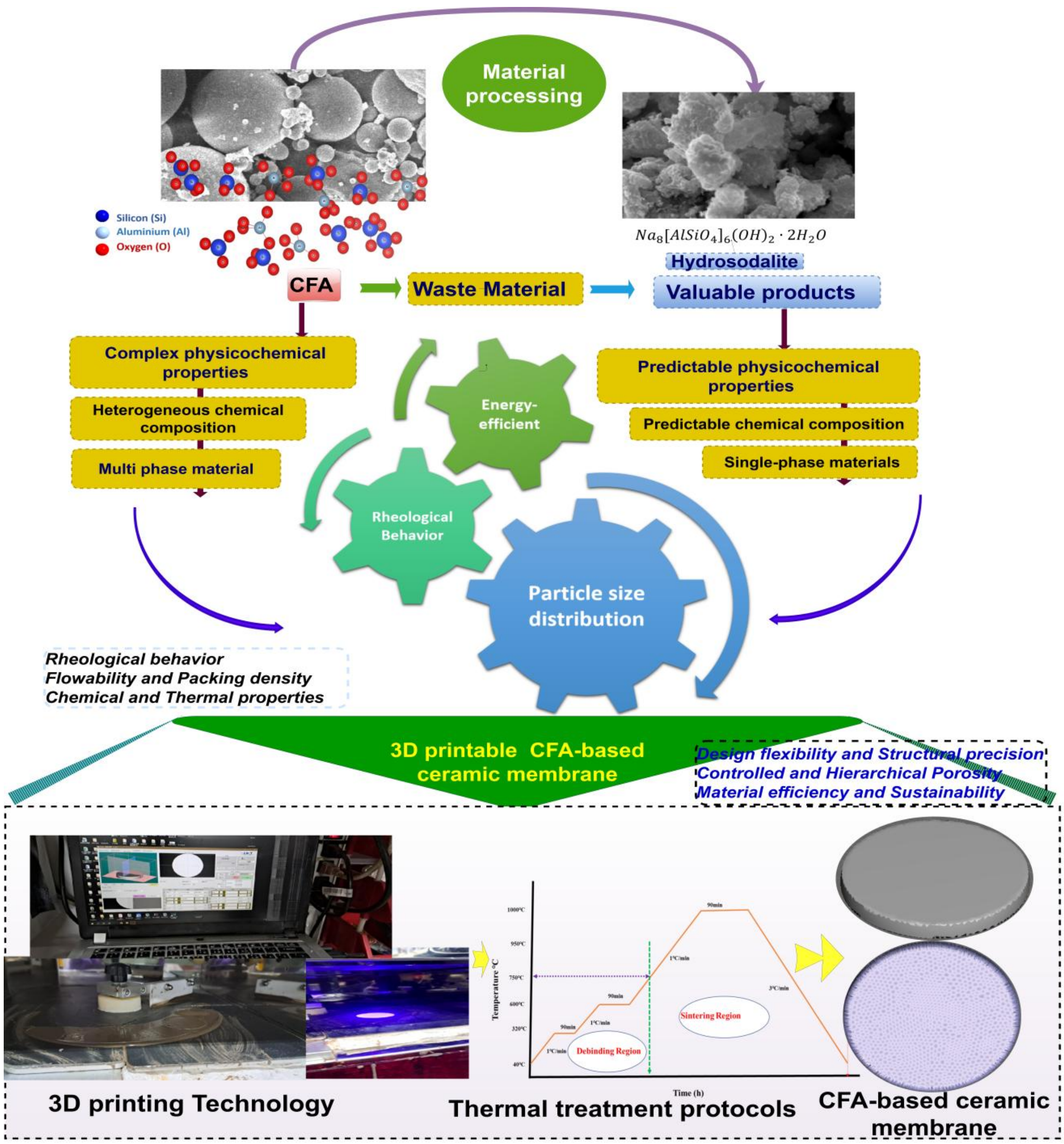
Team members： **Mithilesh Pasawan,** 陳薇安, 詹雅婷

摘要

本研究首創運用 3D 列印技術將廢棄煤灰製成蜂巢狀自支撐無 PFAS 陶瓷膜，應用於廢水處理領域亦可作為生物燃料電池之隔離膜，實現廢水再生與同步發電的雙重功能，突破傳統膜材昂貴具毒性的限制，具環保與應用潛力。

Abstract

With the vision of environmental sustainability, resource recycling and energy generation, in the face of the two major challenges globally-water scarcity and waste overload, a novel strategy is adopted to drive the development of Taiwan's circular economy. A breakthrough PFAS-free, low-cost, 3D-printed ceramic membrane, made from recycled coal ash, is indigenously developed. It withstands harsh chemicals, serving diverse applications like wastewater treatment, and microbial fuel cells. By upcling coal ash, it addresses disposal concerns while enhancing climate resilience, improving water quality, and strengthening infrastructure sustainability.



Material processing
Silicon (Si)
Aluminium (Al)
Oxygen (O)
$Na_8[AlSiO_4]_6(OH)_2 \cdot 2H_2O$
Hydrosodalite
CFA
Waste Material
Valuable products
Complex physicochemical properties
Heterogeneous chemical composition
Multi phase material
Energy-efficient
Rheological Behavior
Particle size distribution
Predictable physicochemical properties
Predictable chemical composition
Single-phase materials
Rheological behavior
Flowability and Packing density
Chemical and Thermal properties
3D printable CFA-based ceramic membrane
Design flexibility and Structural precision
Controlled and Hierarchical Porosity
Material efficiency and Sustainability
Debinding Region
Sintering Region
Time (h)
Temperature °C
3D printing Technology
Thermal treatment protocols
CFA-based ceramic membrane

A. Problem Statement

1. Introduction: In Taiwan, coal combustion contributes to about 37% of the energy demand of the country (Fig 1a). The continuous combustion of coal to meet the energy demands of the population has led to increasing environmental concerns due to the byproduct, coal ash. Therefore, the problem of coal mine combustion waste storage needs to be solved urgently.

On the other hand, coal ash is solid waste rich in ceramic material such as Al_2O, SiO_2, Fe_2O_3, TiO_2, and CaO. Therefore, coal ash waste may be recycled and utilized to produce ceramic membrane thereby alleviating the environmental burden caused by the disposal of coal ash waste while achieving a positive energy cycle and minimizing the cost of raw materials required for developing ceramic membranes. It is worth mentioning that traditional synthesis methods fail to use high proportion of coal ash making the membrane fabrication very complex, therefore, there is a need to develop techniques for mass manufacturing of coal ash membranes.

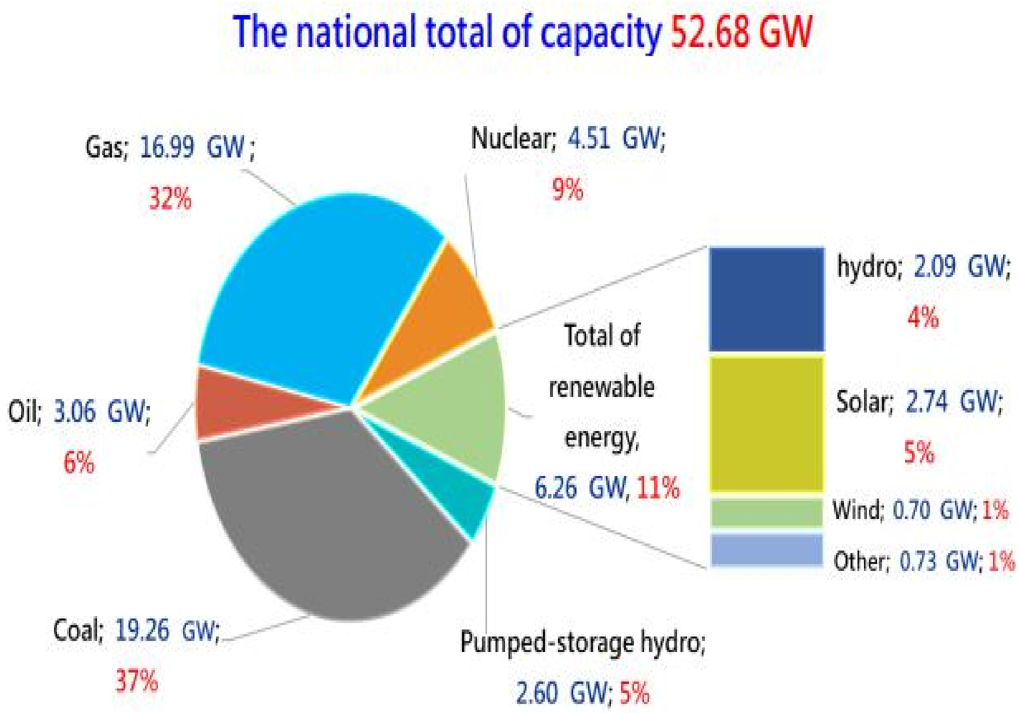


Figure 1a The source and share of national power capacity in Taiwan Data source: Bureau of Energy, MOEA, Energy Statistics Monthly Report, 2019.

The world today is faced with two crises: Water shortage and waste overload. Climate change is the biggest contemporary threat to life which has significantly reduced renewable water resources in many parts of the world. Rising water shortages will hamper economic growth in the context of Taiwan impacting various water-intensive industries such as hydroelectricity, manufacturing, mining, and semi-conducting industry giant TSMC. Reclamation of wastewater to solve the water shortage issue is the need of the hour. However, treatment of industry wastewater is challenging due to the high levels of organic matter that can deplete oxygen in water, disrupt ecosystems, and harm aquatic life.

Microbial Fuel Cells can simultaneously treat wastewater and harvest electricity but it is limited by the cost of the membrane. The commercial Nafion-117 membranes is costly (approx. 1600 USD) and classified as PFAS (Perfluorinated alkylated substances). As Taiwan's Ministry of Environment expedites action to prevent PFAS from damaging the environment and jeopardizing public health, there is an urgent need to fabricate PFAS-free low-cost membrane for wastewater treatment by recycling coal ash waste

2. Motivation and Source of Idea for the project

Motivation: Climate change has substantially diminished renewable water resources globally. Water scarcity slows economic progress which affects industries in Taiwan that rely heavily on water, including hydroelectric power, manufacturing, mining, and companies like TSMC. In Taiwan, the problem of coal mine combustion waste storage needs to be solved urgently. The commercial Nafion-117 membranes is costly and classified as PFAS (Perfluorinated alkylated substances). As Taiwan's Ministry of Environment expedites action to prevent PFAS from damaging the environment and jeopardizing public health, the motivation of this work is to fabricate PFAS-free low-cost membrane by recycling coal ash waste. The development of novel ceramic membranes for wastewater treatment using 3D printing technology is in line with circular economy principles offer dual benefits by not only contributing to the reuse of coal ash thus solving its issue of disposal but also enhancing climate change adaptation by improving water quality and infrastructure resilience.

Source of Idea for the project: The attractive feature of developing ceramic membranes entirely from coal ash wastes rich in Al/Si/O is that, firstly, it minimizes the cost of raw materials. Secondly, unlike the conventional ceramic membrane which involves sintering aids and pore-forming agents during its preparation, no additional step is involved. Thirdly, pretreatment such as acid washing is not required for 3D printing to get rid of K_2O, Na_2O, CaO, MgO, and Fe_2O_3 in CFA responsible for the poor corrosion resistance of ceramic membranes. Fourthly, the manufacturing cost is reduced because of lower sintering temperatures in 3D printing than in traditional inorganic membranes. Overall, the amalgamation of a one-step 3D printing process with coal ash saves time by simplifying the preparation process and reduces the manufacturing cost of ceramic membranes to provide a promising waste-to-resource strategy for effectively utilizing coal wastes. To the best of our knowledge, although ceramic membranes have been previously prepared from composite coal ash,3D printing has not been attempted to develop ceramic membranes using pure coal ash which forms the inspiration of my Doctoral dissertation study.

Goals: The aim of the study is to prepare novel coal ash ceramic membranes for application as proton exchange membrane for simultaneous harnessing electricity and wastewater treatment using Microbial Fuel Cells device using soymilk industry wastewater in Taiwan as feedstock and as separator in treatment of denim jeans industry wastewater in Taiwan.

This main goal will be realized by the specific, particular aims:

1.3D-printing of self-supported patterned and non-patterned membranes from fly ash and bottom ash

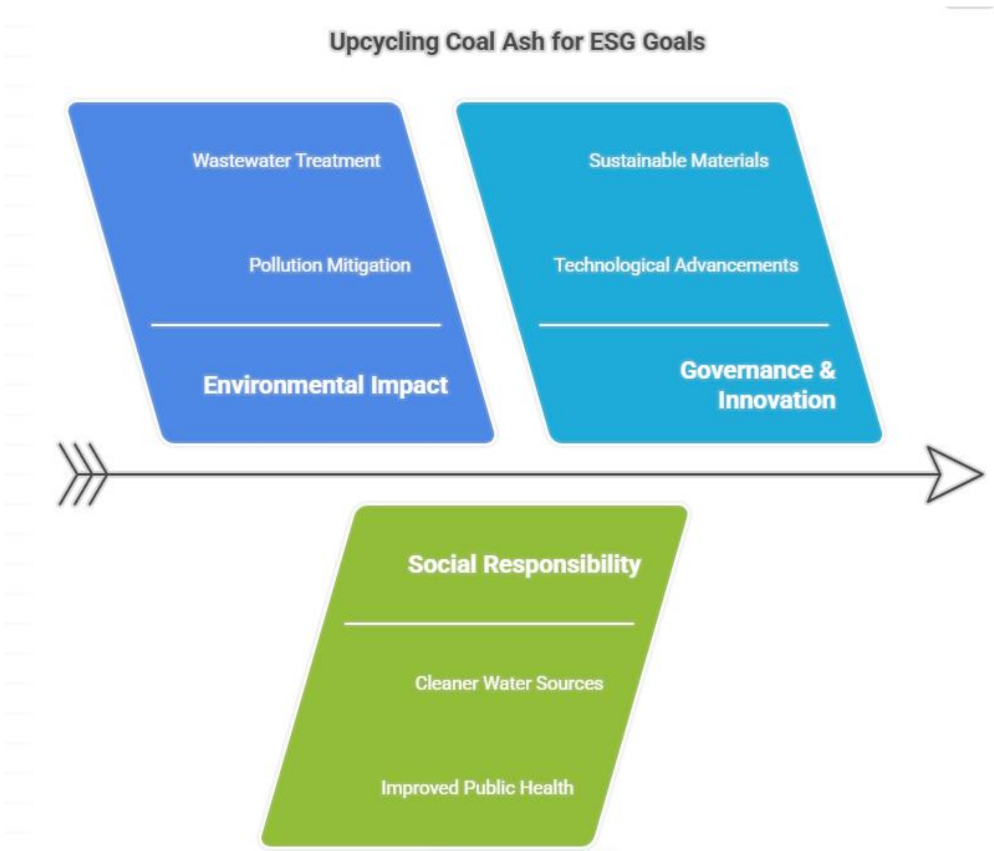
2.Characterization of self-supported ceramic membranes for investigating its feasibility for application in wastewater treatment

3.Application of 3D printed membranes for wastewater treatment: Examination of transport and separation properties, as well as membrane stability – for Microbial Fuel Cells Application to treat wastewater and bioelectricity generation

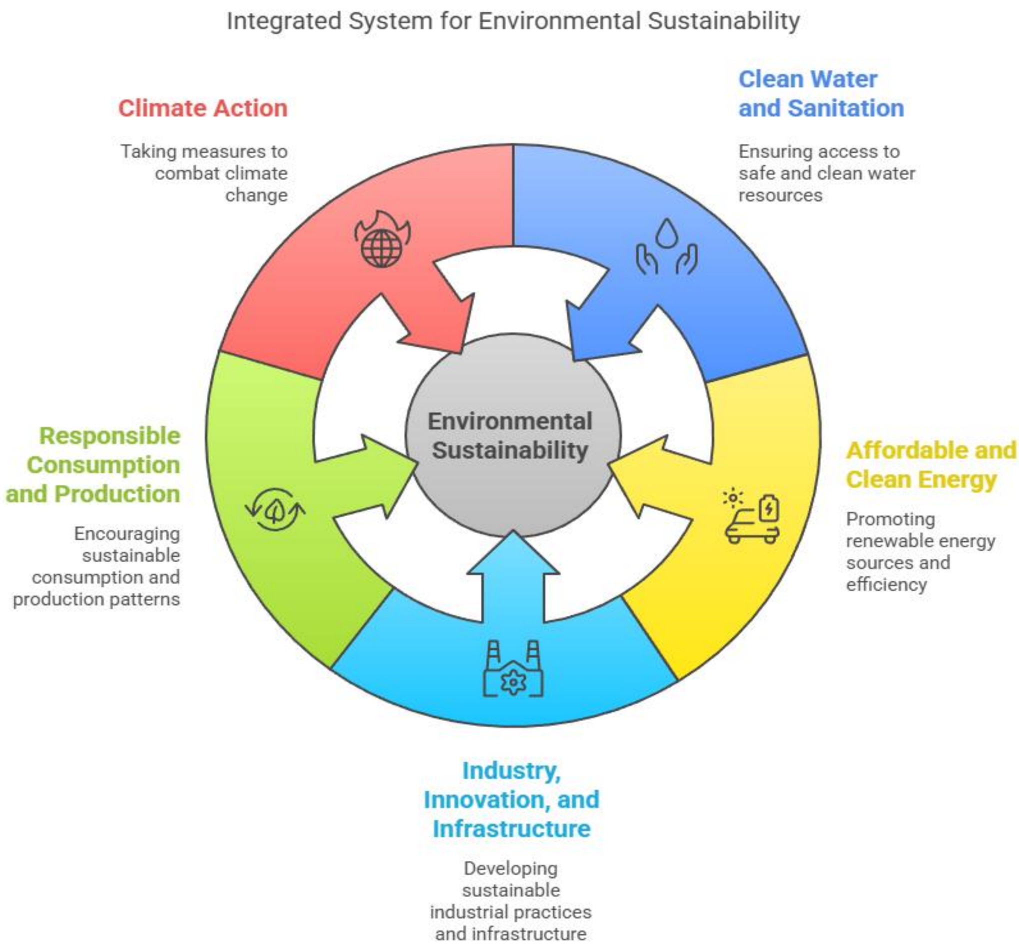
Difference with existing works: The ceramic membrane prepared by 3D printing technology, which reutilizes waste materials such as coal fly ash (CFA) and coal bottom ash (CBA) byproducts resulting from coal-fired power generation (herein also referred to as coal ash, which may be one or more selected from CFA and CBA). The 3D printing may be carried out using Solvent-based Slurry Stereolithography (3S), a technique effective for layer-by-layer fabrication of membranes and capable of building three-dimensional freeform objects with high precision and surface quality based on the operating parameters and working mechanisms, such as rheological behavior, particle size, powder morphology, and layer thickness. The Solvent-based Slurry Stereolithography is suitable for the large-scale manufacturing of self-supported membranes for industrial applications. The slurry used for 3D printing in the present study comprises slurry directly prepared from coal ash, slurry directly prepared from zeolite, or slurry prepared from a mixture of coal ash and zeolite.

Additionally, due to important benefits such as the chemical and thermal stability of ceramic membrane, low fouling propensity, long lifespan, and the ability to address the problems associated with the high cost and toxicity of PFAS fluorinated compounds in many ion exchange membranes, ceramic membranes have become increasingly popular in industries such as water treatment. However, there have been no related work targeting technologies that may reutilize coal ash waste to prepare ceramic membranes and further control the desired silicon content, thickness, porosity, and hydrophilicity/hydrophobicity of the ceramic membranes through the manufacturing process.

Its relation with climate change ESG and SDG : Achieving net zero emissions by 2050 is the objective of Taiwan and most countries in the world. The global water crisis threatens the well-being of billions of people and the stability of nations worldwide. Climate change has significantly reduced renewable water resources in many parts of the world. In response to the 2050 net zero emissions objective, wastewater treatment utilizing ceramic membranes constructed by upcycling coal ash provide two benefits: they improve climate change adaptation by enhancing water quality and infrastructure resilience, and they help to achieve net zero emissions by reducing waste and using sustainable materials.



Coal ash waste upcycling into membranes aligns with **Environmental, Social, and Governance (ESG)** principles by promoting sustainability but also supports sustainable water purification and filtration applications and reducing industrial waste.



This work addresses the environmental challenges of today and supports multiple SDG indicators, specifically, clean water and sanitation (**SDG 6**), affordable and clean energy (**SDG 7**), industry, innovation and infrastructure (**SDG 9**), responsible consumption and production (**SDG 12**), climate action (**SDG 13**) and life on land (**SDG 15**).

3. Description of the work

In the present invention, a novel approach is utilized to bring down the synthesis temperature and produce synthetic zeolite with a high conversion rate and improved crystallinity. A sealed vessel made of Teflon is used in the steel autoclave which automatically lowers the synthesis temperature in comparison to other methods. The samples of coal fly ash (CFA) and coal bottom ash (CBA) are treated with sodium hydroxide (NaOH) and are fused at 140°C prior to conventional raised temperature treatment without stirring as depicted in **Fig. 1b**.

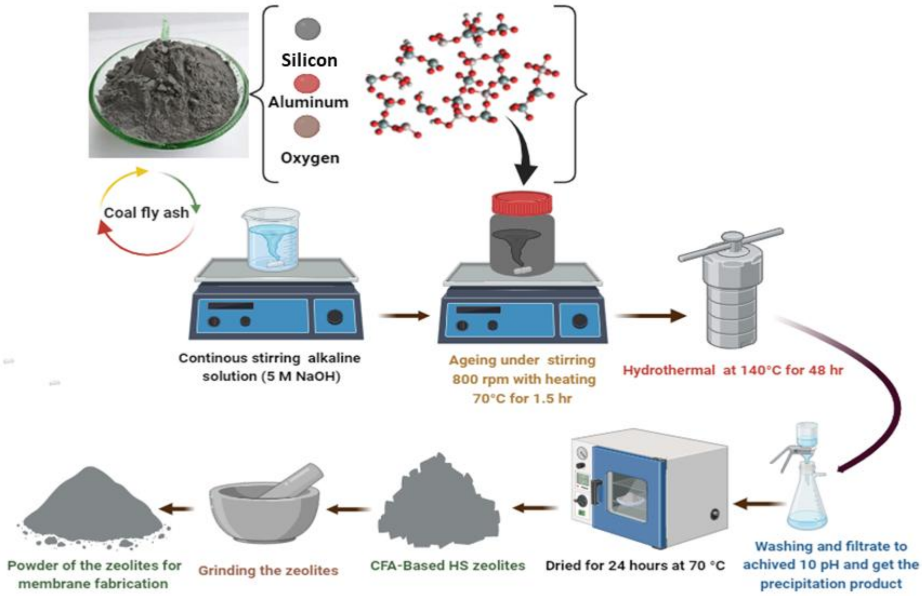


Fig. 1b: Schematic representation of the preparation technique using hydrothermal synthesis from coal fly ash and bottom coal ash to HS zeolite.

The mechanism of the process is complex, involving reactions of dissolution, condensation, and crystallization as illustrated in **Fig. 2**. The first step involves the breaking of Si-O-Si and Al-O-Si covalent bonds transforming itself into a colloidal solution. After this process, the cleaved structures unite with time, forming and generating a condensed structure. As time progresses, the temperature crystallization process leads to the development of polymorphic structures of Na_2SiO_3 and $NaAlO_2$ as shown below to react as per the reactions (1&2) following major three steps, dissolution, condensation, and crystallization (Alterary & Marei, 2021; Yao et al., 2015). To finally obtain the final product hydroxy sodalite as demonstrated below:

$$Al_2O_3 \cdot 2SiO_2 + 10NaOH \rightarrow NaAlO_2 + 2Na_2SiO_3 + H_2O \quad (1)$$

$$6NaAlO_2 + 2Na_2SiO_3 + 8H_2O \rightarrow Na_8[AlSiO_4]_6(OH)_2 \cdot 2H_2O + 10NaOH \quad (2)$$

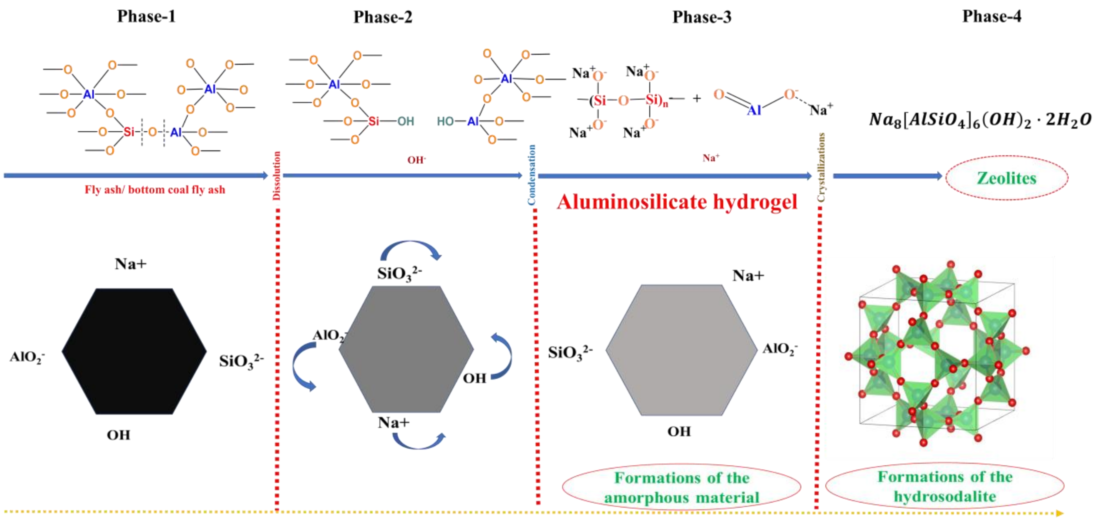


Fig. 2: Mechanism of hydrothermal synthesis of coal ash into HS zeolite.

The present invention claims the successful synthesis of pure phase hydroxy sodalite (HS) zeolite from coal fly ash (CFA) and bottom coal fly ash (BCFA) via a hydrothermal process with the samples produced over a longer synthesis time (48 h) (**Fig 3**).

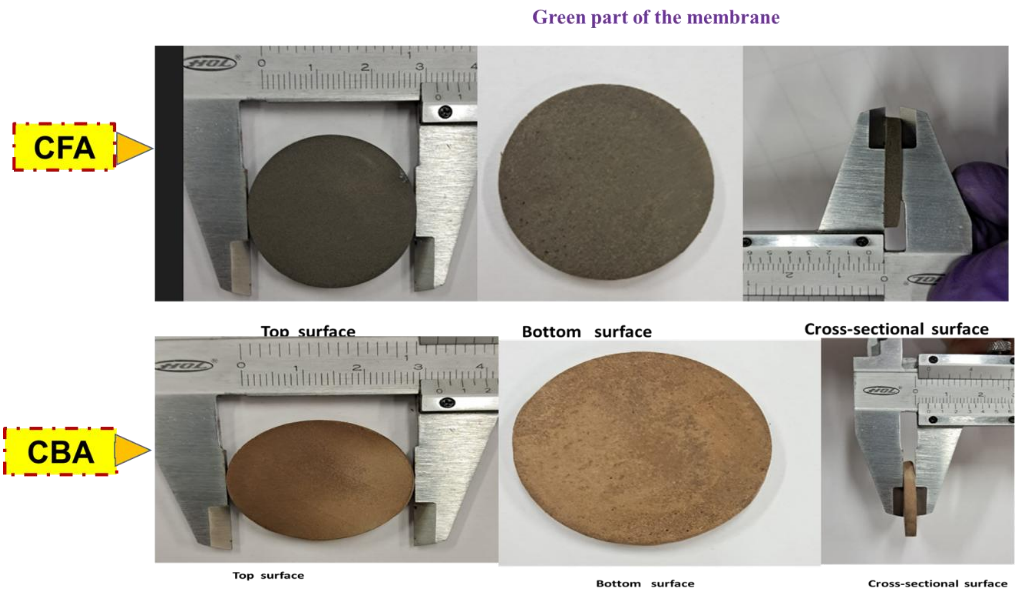


Fig 3: The ceramic membranes obtained from coal fly ash and coal bottom ash via 3D

printing

The formulation for 3D printing is composed of a mixture of coal ash and zeolites (68.14 wt.%), and was mixed with methyl alcohol (9.35 wt.%). The slurry formed green parts when exposed to light. To increase the density of the green parts, only 21.38 wt.% of the photopolymer resin and dispersant (1.1 wt.%), Orange pigment (0.04 wt.%) was added. Methyl alcohol was used as a solvent, and the dispersant was used to evenly distribute coal ash particles to obtain a suitable viscosity. The slurry was formed by mixing the aforementioned materials in optimized percentage compositions. The formed slurry was stored in a cylindrical container, which comprised of zirconia balls (150-160 g), and ball milled. Ball milling was performed at room temperature by rotating the container at 20 rpm for 24 h after that observed the viscosity of the coal ash-derived zeolite higher than the coal ash due to the rough surface and smaller particle size. Thus, the measured viscosity of the coal fly ash and the coal fly ash-derived hydroxy sodalite indicates that an optimum slurry viscosity suitable for additive manufacturing without defect to print was obtained which is an efficient approach for the large-scale fabrication of sub-micron-thick membranes (**Fig 4**).

Optimization of slurry viscosity has been attempted for the first time for the original coal ash and derived zeolites to develop 3D printed bottom coal fly and coal ash-derived membranes. The sintering temperature and thermal debinding of the coal ash and coal bottom ash-based HS zeolite membrane has been optimized (**Fig 5 and Fig 6**). The zeolite synthesized has higher sintering kinetic energy and lower thermodynamic energy compared to the original coal ash membrane. Besides, the activation energy associated with phase transformation for zeolite membrane for hydroxy sodalite formation is drastically reduced as compared to coal fly ash membrane which makes the process economically viable.

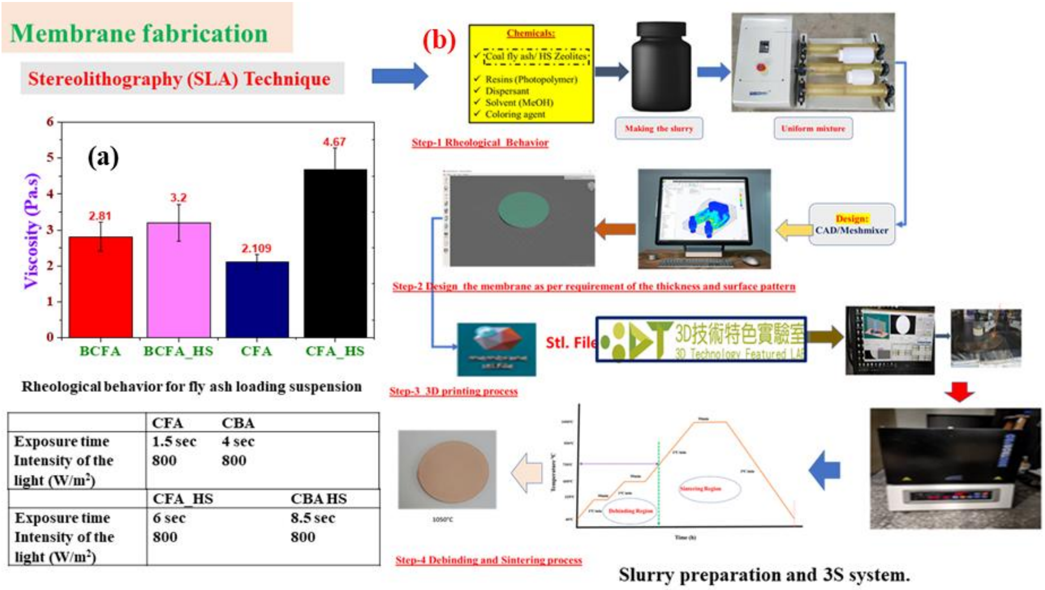


Fig 4: (a)The viscosity of coal fly ash, bottom ash and derived HS zeolites. (b)The 3D printing formulation and the preparation technique of ceramic membranes from coal fly ash and bottom ash and the (a)viscosity.

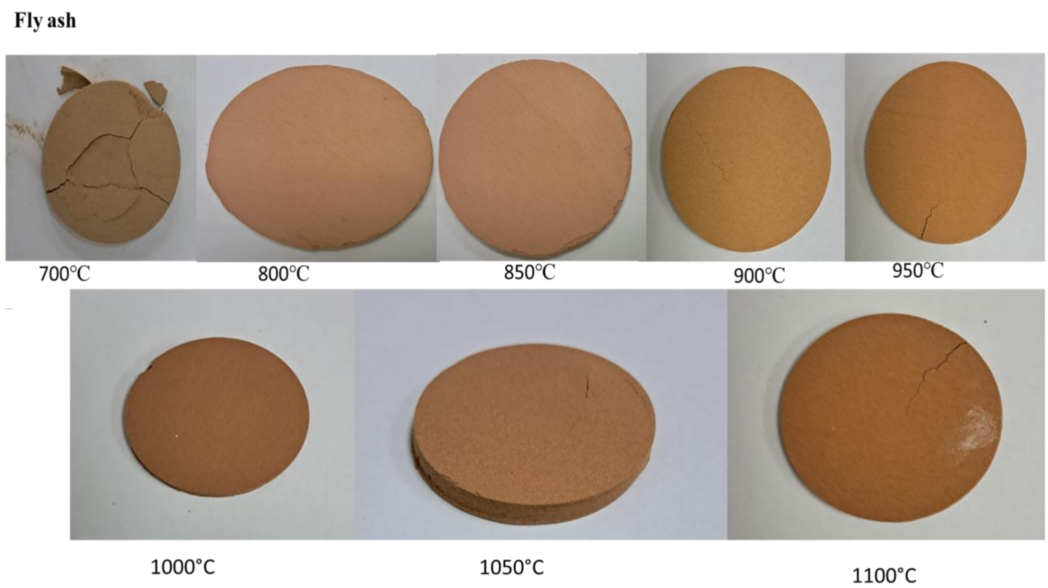


Fig 5: Ceramic membranes from hydrosodalite derived from coal fly ash after optimizing the sintering temperature.

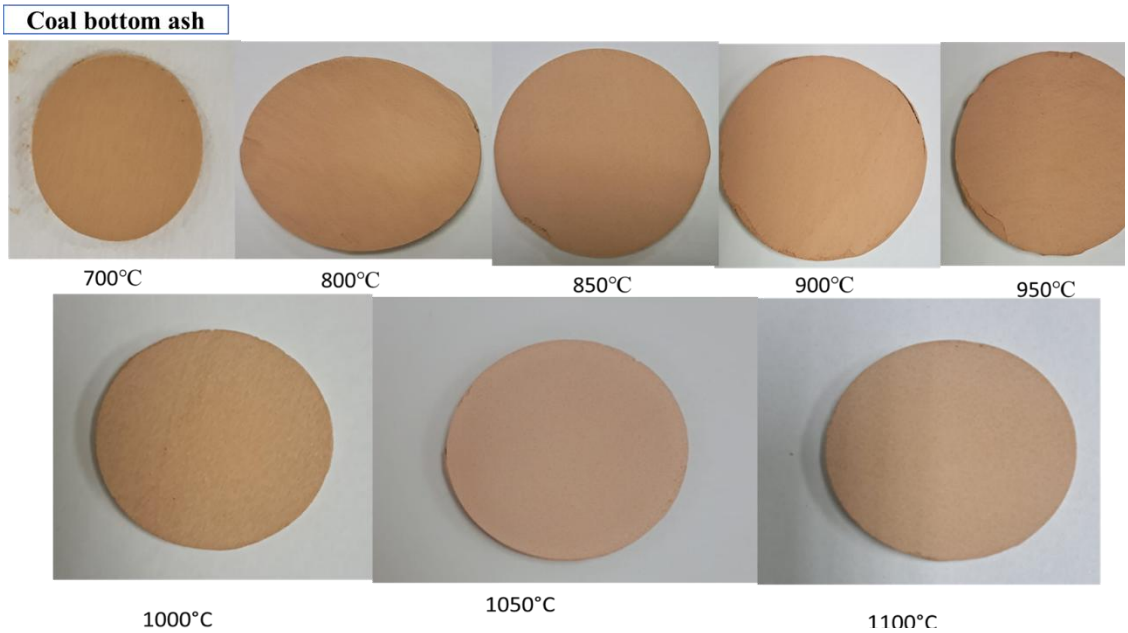


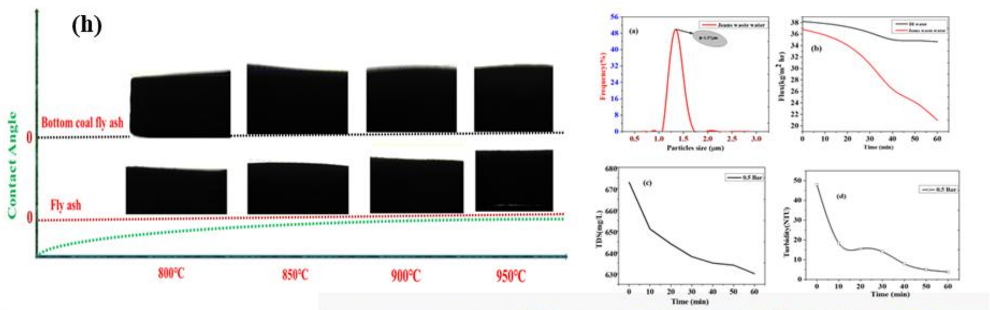
Fig 6: Ceramic membranes from hydro sodalite derived from coal bottom ash after optimizing the sintering temperature.

Another significant aspect is the cost of membranes which affects their industrial applications, which is inversely proportional to the thickness of the membranes. Hence, to economically realize the industrial applications of the 3D printed membranes, their thickness should be optimized. The thickness of the membrane is mainly affected by three factors namely, the viscosity, concentration of the membrane solution and the pore size of the substrate(Zong et al., 2021).

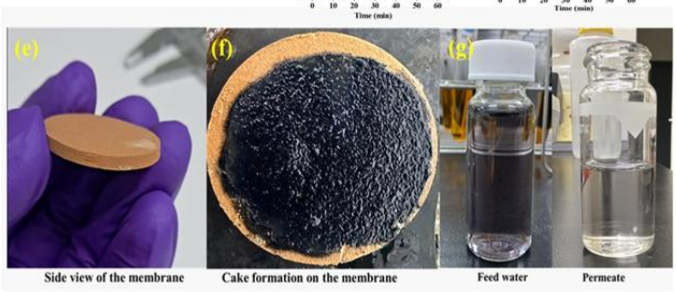
4. Results

The 3D printing machine is developed in the laboratory. The ceramic membranes developed from the 3D printing technology were tested for its practical feasibility to treat industrial wastewater. The membranes were used to treat denim jeans industry wastewater via ultrafiltration, the permeate obtained after the filtration is shown in **Fig 7.** After filtration, the non-dissolve effluent deposited on the membrane surface are observed and the cake formation started to block the open pore. Specific cake resistance of the CFA and CFA-based membrane were 2.06×10^6 m/kg and 3.9×10^9

m/kg and membrane resistance were 2.03×10^4 m^{-1} and 3.4×10^5 m^{-1}. To quantify the results, the flux decline ratio (FDR) and flux recovery ratio (FRR) were determined. FDR and FRR of CFA and CFA based membrane are 0.58, 0.70, and 0.44, 0.17 respectively at a pressure of 0.5-4 bar. To ensure there is no leaching of heavy metals from the membrane, it is sintered at appropriate temperature and the samples are tested using FESEM-EDS. The ceramic membranes developed are super hydrophilic in nature and undergo complete wetting making it suitable for micro to nanofiltration with high flux.



Samples	Turbidity (NTU)	TDS (mgL^{-1})	COD (mgL^{-1})
Feed water	49	673	83
CFA membrane	3.02	619	21
$CFA_{\_HS}$ membrane	2.8	558	10



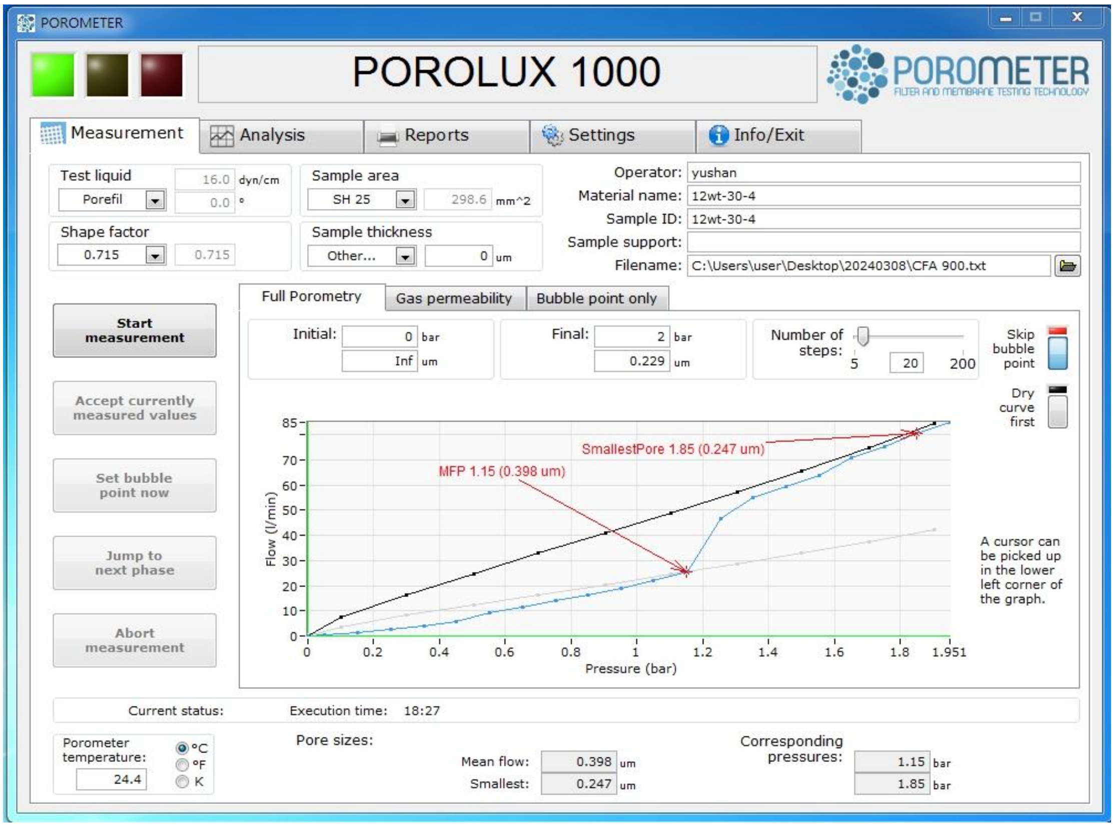


Fig 7: The superhydrophilic ceramic membranes from original coal fly ash and coal bottom ash developed successfully employed as ultrafiltration membrane to treat denim jeans industry wastewater. Pore analysis shows that the pore size within ultrafiltration range

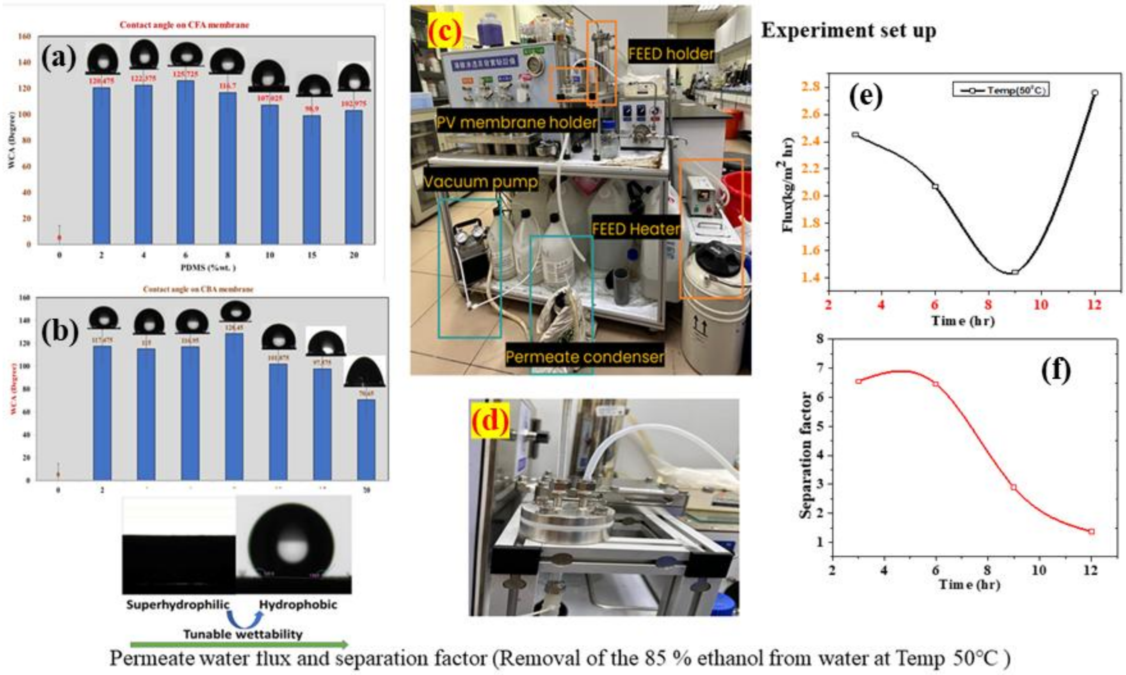
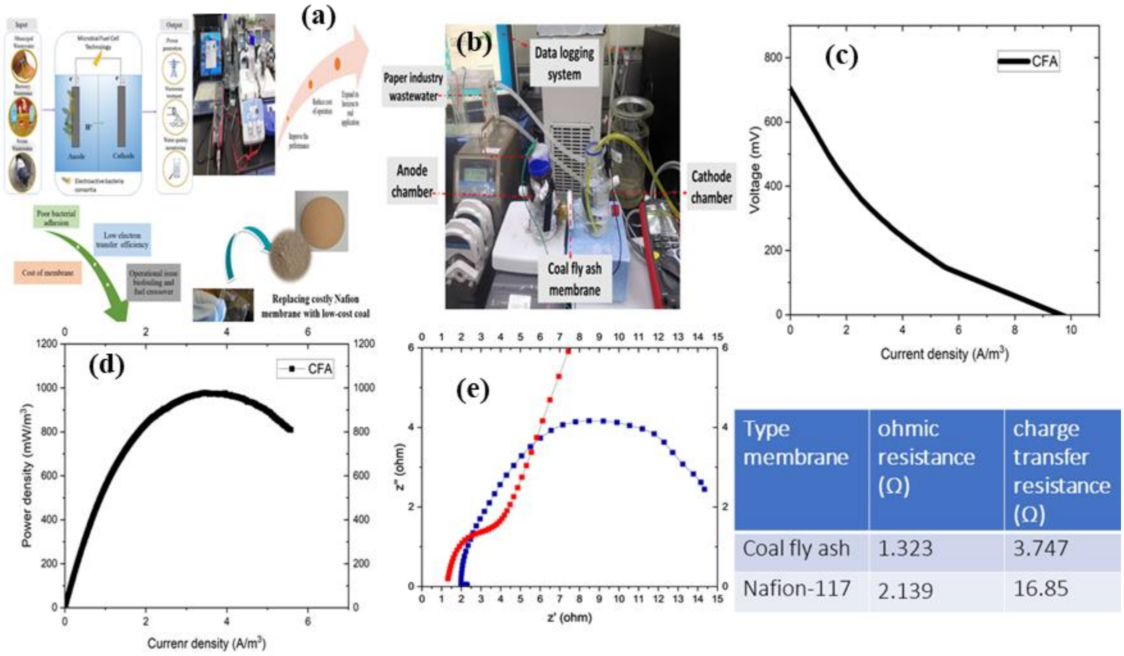


Fig 8. Superhydrophobic ceramic membranes from original coal fly ash and coal bottom ash developed successfully employed as pervaporation membrane to remove ethanol from wastewater.

The biggest advantage is that controlled thickness and pore size can be achieved by 3D printing desirable membranes and hence, broadening the range of applications of economically viable CFA and BCAF-derived ceramic membranes successfully employed as pervaporation membranes as illustrated in **Fig 8**.

The coal fly ash membrane when employed as separator layer in the microbial fuel cell fed with soybean wastewater has successfully harvested power from the wastewater demonstrated by the maximum open circuit voltage (OCV) of 722 mV as shown in **Fig 9**. Use of coal fly ash as filler material has not only enhanced the proton conductivity in CFA but with efficient pore size distribution the crossover of oxygen into the anode chamber reduced drastically (1.4×10^{-3} cm/s) leading to the development of an active electrogenic bacterial community at anode electrode. The higher OCV for the CFA-based MFCs reflects the effectiveness of the designed membrane to selectively allow the passage of protons and suppress unfavorable crossover across the membrane. The maximum current density of 11.76 A/m^3 was observed for the CFA membrane with a maximum power of 977.29 mW/m^3 Low ohmic resistance R_s of 1.323 Ω supports the generation of high-power output and current output values in MFC. The lower charge transfer resistance R_{ct} value of 3.747 Ω.in CFA fortifies the potential of electrogenic biofilm to transfer electrons to the solid electrode surface more efficiently indicating the high presence of redox mediators secreted by electrogenic bacteria in CFA membrane MFC resulting in efficient electron transfer



Type membrane	ohmic resistance (Ω)	charge transfer resistance (Ω)
Coal fly ash	1.323	3.747
Nafion-117	2.139	16.85

Fig 9: The super hydrophilic ceramic membranes from original coal fly ash developed successfully employed as proton exchange membranes to treat soybean industry wastewater and generate power in microbial fuel cell technology.

5. **Cost Evaluation of the technology**: The economic benefit of the next-generation 3D printed product developed is assessed compared to existing technology to know the market potential.

Cost Reduction: ~71% lower material cost using your CFA method.

Next-generation 3D printed product

Component	Amount Used	Estimated Price (USD/g)	Cost (USD)
Coal Fly Ash (CFA)	5 g	~0.01 (usually free, assume small processing cost)	0.05
Photopolymer (e.g., UV resin)	1.6 g	0.4–0.6	0.80
Methanol	0.8 g	0.02–0.03	0.02
Color Pigment	0.003 g	~1.0 (negligible due to low amount)	0.003
Dispersant	0.2 g	0.1–0.2	0.03
Total Estimated Cost			**~$0.90**

Traditional technology

Component	Amount Used	Estimated Price (USD/g)	Cost (USD)
Alumina Powder	5 g	~0.50	2.50
Binder (e.g., PVA)	0.5 g	0.05	0.03
Dispersant	0.2 g	0.1	0.02
Additives	~0.3 g	varies	0.05
Sintering energy	—	— (adds more cost)	~0.50
Total Estimated Cost			**~$3.10**

5. Patented technology and products

A Taiwanese patent has been granted for the innovative ceramic membrane, developed using advanced 3D printing technology, designed for applications in wastewater treatment and microbial fuel cells. While the US patent is under review. The invention’s unique structure and functionality earned it the prestigious MSI Award alongwith 2024 Taiwan Innotech Exp Bronze Medal. An international collaborative TAIWAN Poland project based on the product funded by NSTC has been received in this regard for the year 2022-2024 and currently for 2025-2027.

Taiwan patent

中華民國專利證書

發明第 I871234 號

發明名稱：以3D列印技術製備之陶瓷膜，及其製備方法

專利權人：國立臺北科技大學

發明人：陳孝行、王 民樂、段 博雅

專利權期間：自2025年1月21日至2044年5月7日止

上開發明業經專利權人依專利法之規定取得專利權

經濟部智慧財產局 局長 廖承威

中華民國 114 年 1 月 21 日

注意：專利權人未依法繳納年費者，其專利權自原繳費期限屆滿後消滅。

經濟部智慧財產局　函

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受 文 者：國立臺北科技大學(代理人：黃瑞賢　專利師)

維新國際專利法律事務所
JAN 22 2025
收文章

發文日期：中華民國114年1月21日
發文文號：(114) 智專行（權）證字第11470037700號
1147003770001
速　　別：
密等及解密條件：
附件：如文

主旨：發給第113117077號專利案發明Ｉ871234號紙本專利證書1紙，自民國119年起，每年應於1月20日屆期前繼續繳納年費，請查照。

說明：

一、依113年12月16日所繳證書費及第1至第5年年費辦理。

二、有關本局年費繳納通知僅屬提醒性質，非本局法定義務，嗣後每年年費，不待本局通知，務請依限自行繳納，以維護台端（貴公司）之權益。

正本：國立臺北科技大學
(代理人：黃瑞賢　專利師)

局長 廖承威

<u>ASSIGNMENT OF PATENT APPLICATION</u>

Whereas we, **CHEN, Shiao-Shing**, citizen of **TAIWAN**; **PASAWAN, Mithilesh** and **DAS, Bhanupriya**, citizens of **INDIA** (hereinafter: the "Assignor") are the co-inventors of a certain invention entitled **CERAMIC MEMBRANE PREPARED BY 3D PRINTING TECHNOLOGY AND THE PREPARATION METHOD THEREOF** (hereinafter: the "Invention"), desirous to transfer the entire right, title and interest in and to (1) the Invention, (2) any and all patent applications filed on the invention in any country or jurisdiction worldwide, including but not limited to: (2.1) a Taiwan Patent Application No. **113117077** filed on **8 May 2024**; (2.2) a United States Patent Application filed herewith (hereinafter: the "Patent Applications"); and, (3) to any and all patents which may be granted on the Patent Applications in any country or jurisdiction worldwide (hereinafter: the "Patents"):

And whereas **NATIONAL TAIPEI UNIVERSITY OF TECHNOLOGY**, a university organized under and existing by virtue of the laws of **Taiwan**, and having a place of business at **No. 1, Sec. 3, Zhongxiao E. Rd., Taipei 10608, Taiwan (R.O.C.)** (hereinafter: the "Assignee") is desirous of acquiring the entire right, title and interest in and to the Invention, the Patent Applications and the Patents;

Now, therefore, in consideration of the sum of one dollar ($1.00), and other good and valuable consideration the receipt of which is hereby acknowledged, the Assignor, by these presents, do hereby sell, assign and transfer unto the Assignees the entire right, title and interest in and to (1) the Invention; (2) the Patent Applications; (3) the Patents; (4) any and all divisional, continuation, continuation-in-part, substitute, and reissue applications for Letters Patent resulting from any of the Patent Applications including all priority rights under the Patent Cooperation Treaty (PCT) an International Convention, and all other International Conventions (hereinafter: the "Related Applications").

The Assignor agrees that, when requested, without charge to but at the expense of the Assignees, the Assignor's successors, assigns and legal representatives, in order to carry out in good faith the intent and purpose of this assignment, shall apply for and execute all original, divisional, continuing, continuing-in-part, substitute or reissue patent applications for the Invention; execute all rightful oaths, assignments, powers of attorney and other papers; communicate to the Assignees, its successors, assigns, and representatives, all facts known to the

2025年臺灣-波蘭(NSTC-NCBR)雙邊協議國際合作研究計畫 - 核定補助名單

國科會與波蘭國家研究發展中心(NCBR)共同徵求 2025年雙邊協議擴充加值型(add-on)國際合作計畫，核定補助名單如附件。
計畫執行日期自2025年3月1日起，為期1-3年期，經費核定清單另以公文發送至執行機構。

序號 No.	學術處 Department	臺方計畫主持人 PI in Taiwan	臺方計畫執行機構 Institute in Taiwan	波方計畫主持人 PI in Poland	波方合作機構 Institute in Poland	計畫名稱 Project Title	補助期 Year
1	自然處 Natural Sciences	鄭舜仁 Shun-Jen Cheng	國立陽明交通大學電子物理學系 Department of Electrophysics, National Yang Ming Chiao Tung University	Michal Zielinski	Nicolaus Copernicus University, Toruń, Poland	複合低維半導體中激子能量轉移動力學之研究 Excitonic energy transfer in hybrid low-dimensional materials as a stepping stone towards novel photovoltaic devices.	3
2	自然處 Natural Sciences	謝淑貞 Shuchen Hsieh	國立中山大學化學系 Department of Chemistry, National Sun Yat-Sen University	Igor Iatsunskyi	Adam Mickiewicz University	開發聚多巴胺修飾量子點奈米複合材料用於癌症生物標的物感測 Development of Polydopamine-Modified Quantum Dot Nanocomposites for Advanced Cancer Biomarker Sensing	1
3	工程處 Engineering	陳智 Chih Chen	國立陽明交通大學材料科學與工程學系 Department of Materials Science and Engineering, National Yang Ming Chiao Tung University	Andriy Gusak	Center of Excellence ENSENMBLE3	"Cu/SiO2混合結構在3D IC封裝中熱膨脹行為及熱應力研究 - 建模和實驗的協同作用 A Comprenhesive Study of Thermal Expansion Behavior and Induced Thermal Stress of Cu/SiO2 Hybrid Structures for 3D IC Packaging - a synergy of modeling and experiment	2
4	工程處 Engineering	方冠榮 Kuan-Zong Fung	國立成功大學材料科學及工程學系 Department of Materials Science and Engineering, National Cheng Kung University	Jarosaw Milewski	Warsaw University of Technology	新型雙離子導電性NiO-LSM / NiO-LSCF空氣電極於可逆熔融碳酸鹽燃料電池之性能改善 Development of a novel NiO-LSM / NiO-LSCF air electrode for reversible Molten Carbonate Fuel Cell for performance improvement through double ionic conductivity	3
5	工程處 Engineering	江卓培 Cho-Pei Jiang	國立臺北科技大學機械工程系 Department of Mechanical Engineering, National Taipei University of Technology	Michał Wojasiński	Warsaw University of Technology	陶瓷仿生中空結構設計具有生物活性水凝膠/羥基磷灰石複合填充物以可增強骨整合 Ceramic biomimetic hollow structure design with bioactive hydrogel/hydroxyapatite composite filling for enhancing osseointegration	3
6	工程處 Engineering	辛正倫 Cheng-Lun Hsin	國立中央大學電機工程學系 Department of Electrical Engineering, National Central University	Tadeusz Miruszewski	Instytut Nanotechnologii i Inżynierii Materiałowej, Gdansk University of Technology	鎂-銀-銻-銅-鉍新穎高熵合金的熱電性能優化 Optimization of novel thermoelectric materials based on Mg-Ag-Sb-Cu-Bi high-entropy alloys	3
7	工程處 Engineering	陳孝行 Shiao-Shing Chen	國立臺北科技大學環境工程與管理研究所 Institute of Environment Planning and Management, National Taipei University of Technology	Katarzyna Rychlewska	Intitute of Energy and Fuel Processing Technology	研發新型陶瓷隔離薄膜利用燃煤副產物應用於微生物燃料電池 Novel ceramic proton exchange membranes from coal mining and combustion by-products for coking wastewater fed Microbial Fuel Cells	3
8	工程處 Engineering	Masashi Kotobuki	明志科技大學綠色能源電池研究中心 Battery Research Center of Green Energy, Mingchi Universituy of Technology	Emil Hanc	Mineral and Energy Economy Research Institute of the Polish Academy of Sciences	開發一低成本後鋰電池技術之混成鋰/鈉電池 Development of hybrid Li/Na battery as a low-cost post lithium technology	3

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【專利權人或專利申請人】
國立臺北科技大學
【發明人、新型創作人或設計人】
陳孝行、王民樂、段博雅
【專利】
以3D列印技術製備之陶瓷膜，及其製備方法

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【Patent】
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NATIONAL TAIPEI UNIVERSITY OF TECHNOLOGY
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【發明人、新型創作人或設計人】
陳孝行、王民樂、段博雅
【專利】
以3D列印技術製備之陶瓷膜，及其製備方法

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2024年10月19日於臺北市

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【Patentee/Patent Applicant】
NATIONAL TAIPEI UNIVERSITY OF TECHNOLOGY
【Inventor/Creator/Designer】
CHEN, SHIAO-SHING、PASAWAN, MITHILESH、DAS, BHANUPRIYA

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Award Committee Chair
October 19, 2024, Taipei City

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6.Business Model

Based on the technical feasibility of the product developed, supporting plans for implementation in real field application is strategized as per the following considerations.This product offers a compelling value proposition by transforming coal ash waste into high-performance ceramic membranes with multiple benefits:

Value Proposition: Upcycled coal ash waste into energy-efficient, 3D-printable ceramic membranes for sustainable water purification and electricity generation.

Introduction

Our team has positively added a new facet to the design of low-cost membrane material by not only developing desirable membranes with controlled thickness and pore size that can be achieved by 3D printing but also, has demonstrated the vast potential of wastewater treatment from micro to nanofiltration particularly for people in remote areas who do not have access to clean water and electricity. The use of coal ash to achieve a zero waste production economy can not only solve Taiwan’s coal ash waste disposal issue. It will solve the problem of landfills required to discard the waste and also the high waste disposal cost. Most importantly, the application of

3D-printed ceramic membranes in Microbial Fuel Cells as a low-cost alternative to the high-cost fluorinated membranes demonstrates the potential of our membrane for wastewater treatment, nutrient recovery, power harvesting as well as green hydrogen generation in Taiwan.

Cost and Energy Efficiency: The use of hydrosodalite zeolite (HS zeolite)derived from coal ash significantly lowers the thermal treatment costs of ceramic membranes. Since it requires less energy-intensive processing, it makes membrane fabrication more sustainable and cost-effective.

Commercial Viability with 3D Printing: The higher viscosity and sintering rate of HS zeolite enable efficient 3D printing of ceramic membranes, paving the way for scalable production. This innovation enhances feasibility for mass manufacturing, making advanced filtration systems more accessible.

Energy Generation from Wastewater: An exciting feature of the fabricated membrane is its ability to generate electricity from wastewater when used as a separator layer in a Microbial Fuel Cell (MFC). This function supports clean energy production and opens new possibilities in waste-to-energy technologies.

Environmental and Sustainability Impact: By upcycling coal ash waste, this technology not only reduces industrial waste but also supports sustainable water purification and filtration applications, contributing to ESG goals.In response to the **2050 net zero emissions** objective, wastewater treatment utilizing ceramic membranes constructed by upcycling coal ash provide two benefits: they improve climate change adaptation by enhancing water quality and infrastructure resilience, and they help to achieve net zero emissions by reducing waste and using sustainable materials.Furthermore,this work addresses the environmental challenges of today and supports multiple **SDG** indicators, specifically, clean water and sanitation (**SDG 6**), affordable and clean energy (**SDG 7**), industry, innovation and infrastructure (**SDG 9**), responsible consumption and production (**SDG 12**), climate action (**SDG 13**) and life on land (**SDG 15**).

Market Adoption strategy : Our customers are likely organizations and industries that prioritize sustainability, cost efficiency, and innovative environmental solutions. Based on the cost analysis, 71% reduction in the cost is achieved by transforming coal ash waste w.r.t commercial membranes. A breakdown of potential target markets and customers are as follows:

a) Water Treatment Facilities: Companies focused on wastewater purification will benefit from ceramic membranes with enhanced filtration and energy-efficient properties.

b) Energy Sector & Microbial Fuel Cell Developers: Businesses and research institutions working on waste-to-energy technologies can utilize the membrane for electricity generation from wastewater.

c)Industrial Manufacturers & 3D Printing Innovators: Industries exploring advanced ceramic materials for filtration and infrastructure applications will see value in the 3D-printable membrane technology.

d)Government & Sustainability Organizations: Agencies promoting ESG-friendly solutions may adopt these membranes for environmental projects, especially in developing clean water systems.

e) Chemical & Pharmaceutical Processing: Sectors requiring high-performance filtration for liquids and gases will find utility incoal ash-derived ceramic membranes.

Global solutions: Based on the technical expertise of the team, the product developed can cater to global issue of coal ash disposal specially in Taiwan which meets 37 % of its energy demands using coal from coal-fired thermal power plants. The team specializes in Environmental Engineering and Management with a strong background in Chemical Engineering. The team membranes have hands-on experience in 3D printing technology, membrane fabrication, water quality analysis and fuel cell testing.

Key Partners Semiconductor industry Municipal Wastewater treatment Water company Desalination industry	**Key activities** Pilot scale testing Product marketing and branding	**Value Proposition** Low-cost Recycled material PFAS-free Tuned thickness Tuned porosity	**Customer Relationship** **Membership limit**	**Customer segments** **Wastewater type reclamation**
	Cost structure Equipment maintenance cost Labour cost	**Revenue Streams** Selling of Membrane Wastewater analysis		

Summary

In summary, the present work is a novel attempt to fabricate 3D printed low-cost ceramic membranes to solve the issue of recycling coal-fired power plant waste. The ceramic membranes developed are a promising alternative to PFAS containing polymeric membranes for selective separations, given their ability to operate under harsh chemical conditions. Together with its tunable porosity, ranging from dense structure to subnanometer porous structure, and its tunable wettability ranging from superhydrophilicity to super-hydrophobicity, for broad range application of treating complex industrial wastewater using microfiltration to pervaporation application