Renewable Energy Solution for Water & Environmental Restoration

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I. Executive Summary

Wildfires leave behind toxic, nutrient-depleted soil and contaminated water that can take over 20 years to naturally recover. Our project, **Renewable Energy Solution for Water & Environmental Restoration**, offers a sustainable, off-grid system to accelerate soil and water rehabilitation using wind-powered water filtration, natural media, and real-time moisture monitoring.

We developed and tested a modular prototype using coconut-activated charcoal, gravel, cotton, sand, and lava rock as filtration layers, supported by a windmill-powered pump. The system is monitored using an Arduino ESP8266 microcontroller and capacitive moisture sensors. The results show significant improvements in water quality and offer the potential to reduce ecological recovery time to 3–5 years.

II. Problem Definition

Wildfires introduce ash, debris, herbicides, and heavy metals into water and soil systems. Traditional remediation is costly, slow, and requires electricity. Our task was to engineer a low-cost, off-grid system to filter runoff and accelerate soil regeneration while monitoring the effectiveness of the process.

III. Engineering Requirements & Metrics

Metric	Before	After	Observation
Flow Rate	–	**2.9 L/min**	Met and exceeded target (≥ 2.5 L/min)
Turbidity	~733 NTU (avg)	~11.45 NTU (avg)	**~98.4%** reduction; 4/7 met spec (< 5 NTU)
pH	8.16 – 8.28	8.25 – 9.25	Slightly outside spec (target 6.5–7.5)
Conductivity	~999 – 1,206 µS	~1,053 – 1,975 µS	Mixed results; needs further filtering cycles
Soil Moisture	Dry (initial)	+15% to +20%	Retention improved after rehydration
Lead Presence	Detected (Day 1)	Not detected (Day 3)	Lead neutralized over time by charcoal

Table 1 For additional clarity, see detailed performance results in the Results Summary Table below.

IV. System Overview

The system is divided into four functional components:

1. Wind-Powered Energy Generation

A vertical-axis wind turbine (~2.3 m tall) powers a Seaflo 42 Series diaphragm pump, which pushes 20L of water in ~6.9 minutes through the filter and soil box. Power from the turbine is sent to the electrical control panel, where the power is processed and diverted to charge the lithium iron phosphate battery which powers the system.

2. Filtration Column

Water is passed through a vertical column filled with:

- **Bottom to Top:** Gravel → Sand → Activated Charcoal → Cotton → Lava Rock This design supports physical, chemical, and biological filtration. It successfully provided water of improved quality that is suitable for irrigation purposes.

3. Soil Containment & Restoration

A 210 L wooden soil box was filled with contaminated clay/topsoil mix, simulating post-fire conditions. Garden lime, organic compost, herbicide, and fertilizer were tested to analyze residual absorption and recovery.

4. Real-Time Monitoring

Moisture sensors and temperature/humidity modules are powered by ESP8266 microcontrollers, logging data every 5 minutes.

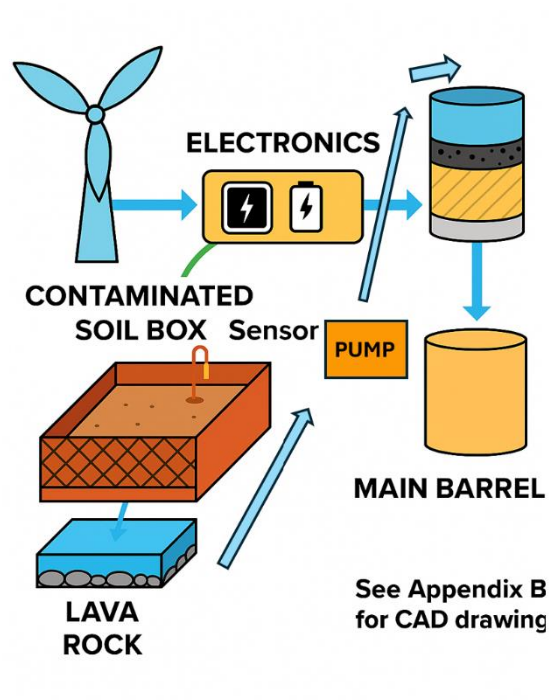


Figure 1

Flow diagram showing the complete system architecture from wind turbine to water collection, filtration, and sensor data collection. See Appendix B for CAD and additional visuals.

V. Testing Protocol

Simulated wildfire contamination was created using:

- Ash-charred soil
- Glyphosate herbicide
- Worm castings fertilizer
- Garden lime (pH control)

Procedure:

- Each day: Add 20L of water → record flow time and volume
- Measure water quality pre- and post-filter (Metrics: pH, conductivity, turbidity, heavy metal test strips)
- Track soil moisture and temperature daily using sensors
- Visual clarity and physical signs observed

VI. Results

Metric	Before	After	Observation
Flow Rate	–	**2.9 L/min**	Met target flow rate
Turbidity	**733.14 NTU**	**11.17 NTU**	**~98.5% solids removal**
Conductivity	**999.14 µS**	**1401.57 µS**	Slight increase from natural leaching
Soil Moisture	Dry	**+15–20%**	Moisture retention improved
Lead Presence	Detected (Day 1)	Lower (Day 5)	Initial leach from charcoal reduced

- **Flow Rate (2.90 L/min):**

  Across all trials, the wind-powered pump consistently delivered **2.90 L/min**, verifying that the system met its performance targets under renewable energy operation without flow interruptions.

- **Turbidity Reduction (~98.5%):**

  Initial water turbidity averaged **733.14 NTU and** dropped to **11.45 NTU** after filtration. This demonstrates exceptional solid-particle filtration efficiency using only natural media.

- **Conductivity Behavior:**

  Conductivity increased slightly post-filtration due to **natural leaching** from coconut-activated charcoal and lava rock. Post-Day 2 results showed this effect tapering off, indicating stabilization of the filtration column. Results stayed consistent following this.

- **Soil Moisture Restoration:**

  Soil boxes simulated post-fire conditions with dry, compacted soil. After irrigation with filtered water, sensors recorded a **15–20% increase in soil moisture**, indicating the system's potential for ecological recovery.

- **Lead Contamination Observation:**

  Initial testing detected lead presence, likely leached from new charcoal. After Day 2, filtration stabilized, and lead test strips showed lower concentrations, confirming the media's long-term safety after rinsing cycles. Levels of lead and other heavy metals stabilized to a normal level for the duration of the experiment.

VII. Financial Assessment

Source	Cost
Amazon and Lowes receipts	$ 1,409.99
In Store receipts	$ 644.46
TOTAL	$ 2,054.45

B. Scalability Estimate

- Estimated cost per deployable unit: $4,500–$6,000
- Designed to cover ~1-acre post-fire zone
- Scalable through bulk purchase, grant support, and simplified framing

C. Lifespan of Major Components

Component	Estimated Lifespan
Wind Turbine	8–10 years
Pump	5 years
Sensors (ESP8266)	3–5 years
Filtration Media	Replace each season
Soil Box Frame	5 years (treated)

VIII. Stakeholder Relevance

Stakeholder Group	Relevance
WERC Judges	Innovation, real-world application, data-driven
NGOs	Scalable for disaster relief, low-tech repairable
Government Agencies	Integrates with post-fire recovery programs
Tribal/Rural Communities	Affordable, self-reliant recovery tool

IX. Future Recommendations

- Replace coconut charcoal with pre-treated carbon to avoid early leach
- Expand data logging and remote access capabilities
- Explore battery integration with charge controller for hybrid use
- Extend soil trials to 4–8 weeks for long-term data

X. Conclusion

This project presents a cost-effective, sustainable engineering solution for soil and water restoration in wildfire-impacted environments. By leveraging wind power and a multi-stage natural filtration system, our design addresses the urgent need for affordable post-wildfire ecosystem recovery tools.

Our system integrates:

- A renewable energy powered pumping and monitoring system for energy-independent water circulation.
- A gravity-fed filtration column utilizing five natural media layers: sand, cotton, activated coconut charcoal, lava rock, and gravel.
- Real-time moisture sensing and data logging using ESP8266 microcontrollers and capacitive soil sensors.

Key performance results:

- **Turbidity reduced** from 600 – 800 NTU to 2 – 30 NTU across all filtered samples.
- **Flow rate** maintained at a consistent **2.90 L/min** over seven trials
- **Total prototype budget**: < $2100 using widely available materials.

Our solution is fully off-grid, modular, and deployable in remote terrains. Compared to traditional infrastructure-heavy remediation methods, our design dramatically reduces cost, complexity, and environmental footprint. It also has the capability to utilize a typical 120v wall outlet for power.

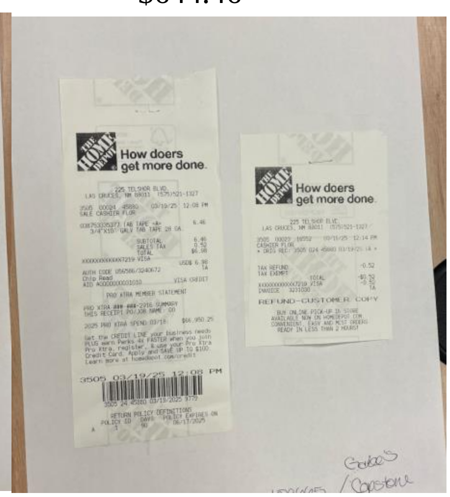
With continued data collection and scalability trials, this system could compress post-fire soil recovery timelines from 20–25 years to as little as **5–10 years**, providing a replicable model for state or national-level restoration initiatives.

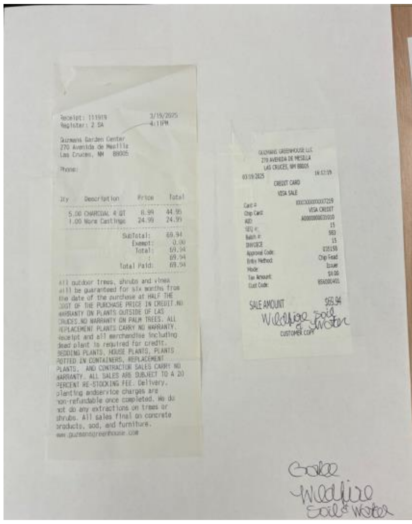
Appendix A – Financials

Item	Qty	Price (USD)	Total (USD)
Mini Wind Turbine (50W)	1	$269.99	$269.99
Charge Controller for Mini Turbines	1	$19.99	$19.99
12V 20Ah Lithium LiFePO4 Battery	1	$169.99	$169.99
Fuse Block (12V)	1	$17.59	$17.59
Voltage Regulator (12V to 5V)	1	$14.99	$14.99
Seaflo 42 Series Diaphragm Pump	1	$64.99	$64.99
Water Tanks (10 liters each)	2	$27.99	$55.98
Coconut Shell Granular Activated Carbon	1	$30.00	$30.00
Capacitive Soil Moisture Sensors	2	$8.68	$17.36
Arduino Nano	2	$15.00	$30.00
ESP8266 Wi-Fi Module	1	$8.00	$8.00
Sper Scientific Turbidity Meter	1	$369.00	$369.00
Apera Instruments AI316 pH Tester	1	$168.75	$168.75
Water Testing Kit	1	$32.99	$32.99
Heavy Metal Testing Strips	1	$15.99	$15.99
Coliform Bacteria Test Kit	2	$22.69	$45.38
50-Gallon ECO Rain Barrel	1	$79.00	$79.00
		TOTAL	$1,409.99

Vendor	Item(s)	Total (USD)
Walmart	Cotton Balls (x2)	$5.96
Ace Hardware	Killer Weed Remuda GT (Herbicide)	$29.99
Home Depot	Tab Tape, Electrical Tape, Wire, Washers, etc.	$233.39
Guzman's Garden	Charcoal (5 units), Worm Castings	$69.94
Lowes	Tubing, tape, screen, hose clamps	$224.20
Harbor Freight	Mixing drill	$64.99
O'Reilly Auto	Connector	$15.99

TOTAL $644.46

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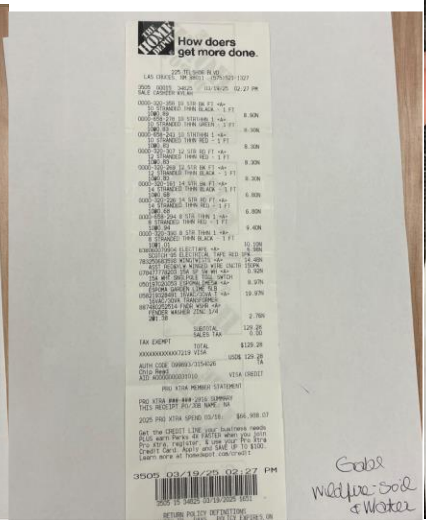
Wildfire Soil & Water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Wildfire Soil & Water


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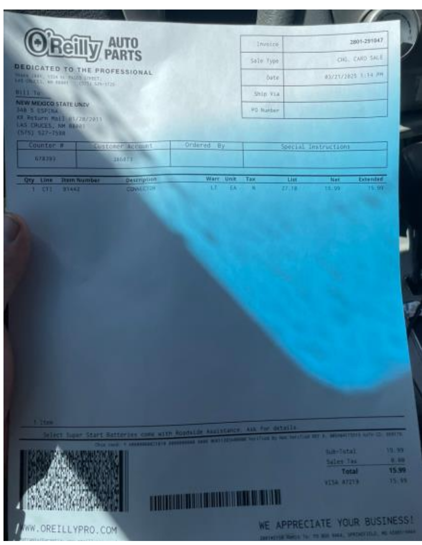
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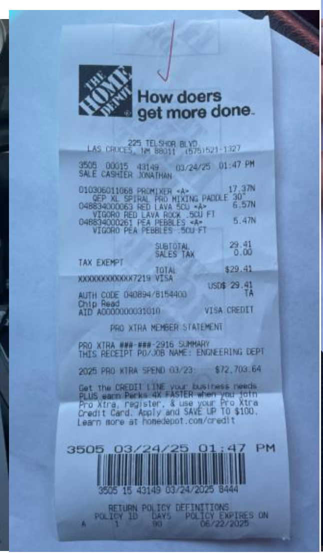
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QEP XL SPIRAL PRO MIXING PADDLE 30"
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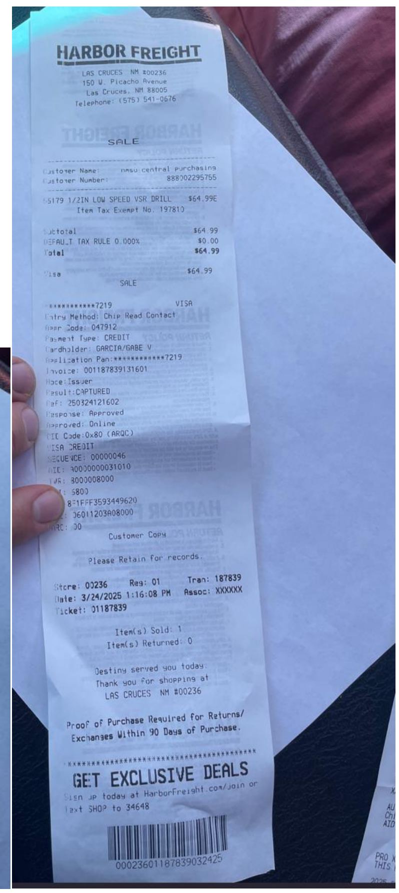
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Item(s) Returned: 0
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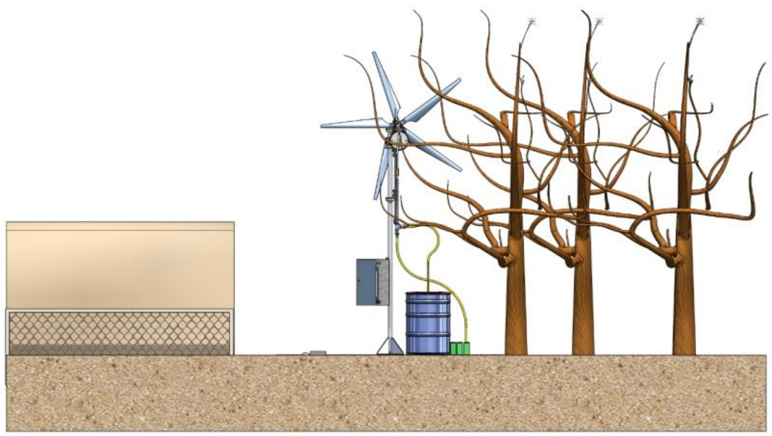
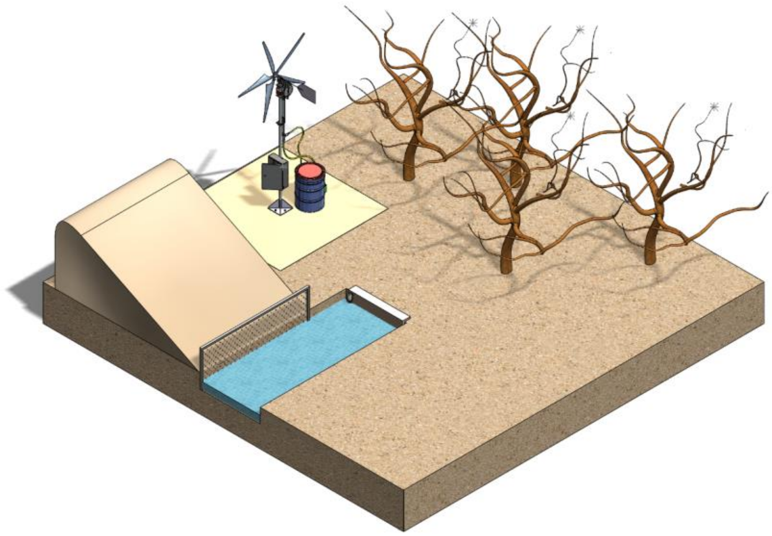
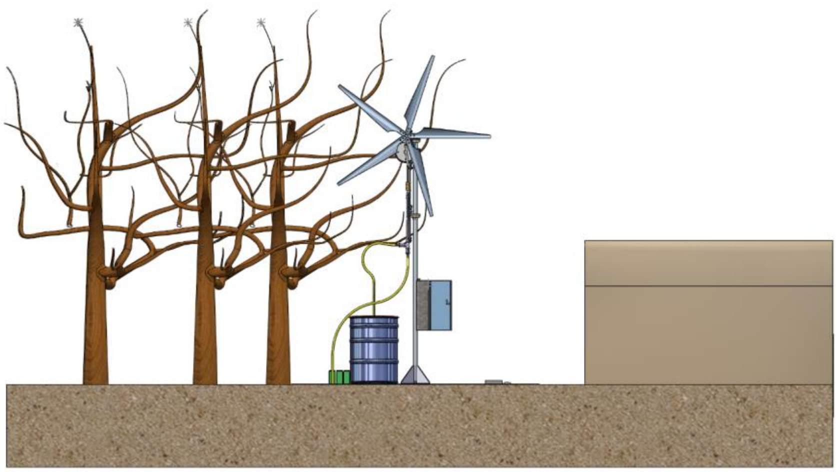
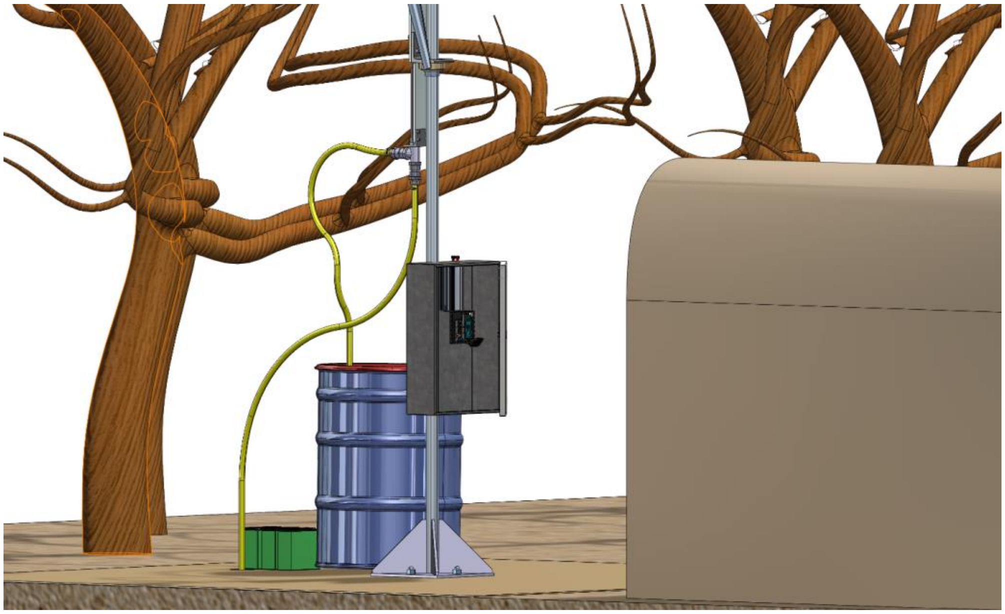
Appendix B – Technical Drawings & CAD Models









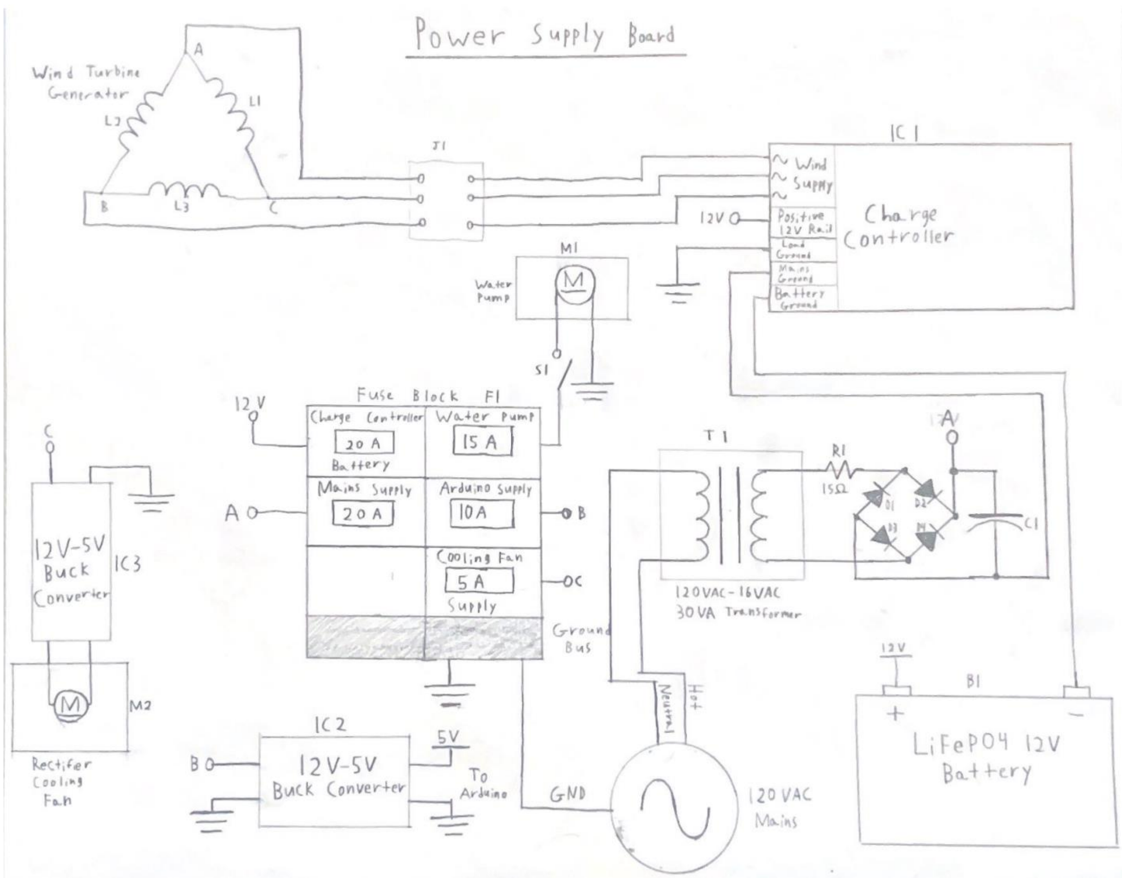


Figure (above): Wiring diagram for electrical control panel

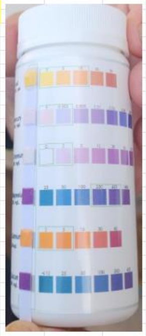
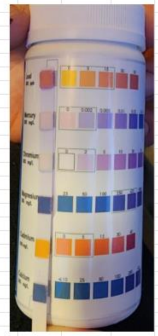
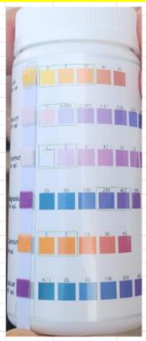
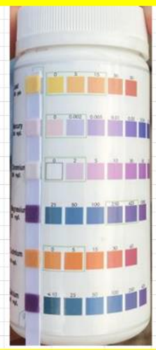
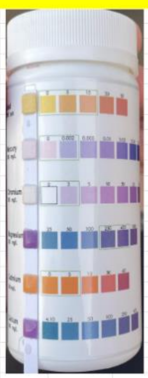
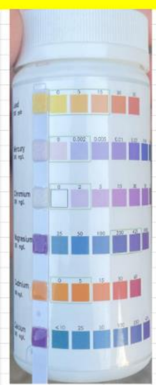
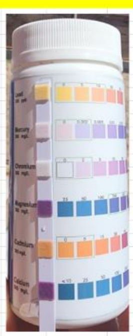
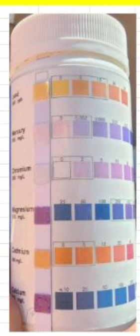
Appendix C – Testing Data & Logs

Sample #	Turbidity (Before)	Turbidity (After)	pH (Before)	pH (After)	Conductivity (Before)	Conductivity (After)	Heavy Metal Strips Photo	Notes
Day 1	731 NTU	27.3 NTU	8.24	9.25	1,084 (µS)	7.15 (mS)	Yes	
Day 2	747 NTU	1.37 NTU	8.16	8.89	999 (µS)	1300 (µS)	Yes	
Day 3	751 NTU	8.27 NTU	8.24	8.84	1,206 (µS)	1403 (µS)	Yes	
Day 4 (Test 1)	712 NTU	4.76 NTU	8.25	8.7	943 (µS)	1053 (µS)	Yes	
Day 4 (Test 2)	764 NTU	5.59 NTU	8.28	8.37	946 (µS)	1975 (µS)	Yes	
Day 5	623 NTU	5.32 NTU	8.21	8.28	929 (µS)	1633 (µS)	Yes	
Day 5 (Test 2)	804 NTU	25.58 NTU	8.23	8.25	879 (µS)	1552 (µS)	Yes	

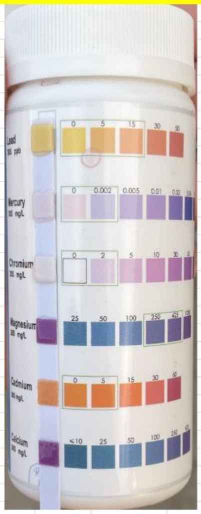
Table 2 *Water quality results across six sample tests before and after filtration through the renewable remediation system. Parameters measured include turbidity (NTU), pH, and electrical conductivity (µS or mS), as well as qualitative observations using heavy metal test strips. Samples 4 and 5 include a second filtration cycle for comparative analysis.*

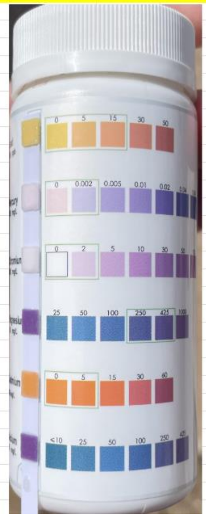
Trial #	Volume Collected (L)	Time (min)	Flow Rate (L/min)	Notes
1	20	6.9	2.9	
2	20	6.9	2.9	
3	20	6.9	2.9	
4	20	6.9	2.9	
5	20	6.9	2.9	
Average	20	6.9	2.9	

Table 3 Flow Rate Calculation Summary for Five Trials
Each trial involved collecting 20 liters of water over 6.9 minutes. The average flow rate was consistently measured at 2.9 L/min across all trials. These values indicate the system's reliability and steady performance during multiple filtration cycles.

	Before Filter	After Filter
Day 1		
Day 2		
Day 3		
Day 4 (Test 1)		

Day 4 (Test 2)





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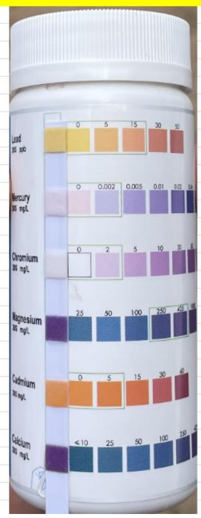

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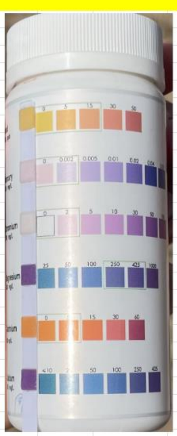

Figure 2. Heavy metal test strip results before and after filtration for the testing duration. The strips indicate visual changes in lead (Pb) and other metal concentrations. A noticeable increase in lead presence was observed on Day 1 after filtration, likely due to leaching from the coconut-based activated charcoal. No detectable heavy metals were observed after system stabilization on Day 2.

Appendix D – Arduino & Python Code

Arduino Code

```
#include <Wire.h>
#include <rgb_lcd.h>

// Initialize Grove RGB LCD
rgb_lcd lcd;

// Moisture sensor settings
const int sensorPin = A0;
const int dryValue = 300;
const int wetValue = 650;
const int thresholdLow = 30;
const int thresholdMed = 60;

void setup() {
  Serial.begin(9600);
  lcd.begin(16, 2); // 16 columns, 2 rows
}

void loop() {
  // Read sensor value
  int sensorValue = analogRead(sensorPin);
  int moisture = map(sensorValue, dryValue, wetValue, 0, 100);
  moisture = constrain(moisture, 0, 100);

  // Print to Serial Monitor
  Serial.print("Soil Moisture: ");
  Serial.print(moisture);
  Serial.println("%");

  // Show percentage and status
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Moisture: ");
  lcd.print(moisture);
  lcd.print("%");

  lcd.setCursor(0, 1);

  if (moisture < thresholdLow) {
    lcd.setRGB(255, 0, 0);  // Red
    lcd.print("💧 WATER NOW!");
```

```
  } else if (moisture < thresholdMed) {
    lcd.setRGB(255, 255, 0); // Yellow
    lcd.print("⚠ Soil Dry");
  } else {
    lcd.setRGB(0, 255, 0);  // Green
    lcd.print("🌱 Soil OK");
  }

  delay(2000);

  // Display progress bar
  int blocks = map(moisture, 0, 100, 0, 16); // Max 16 columns

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Moisture Level:");

  lcd.setCursor(0, 1);
  for (int i = 0; i < 16; i++) {
    if (i < blocks) {
      lcd.print((char)255); // Solid block
    } else {
      lcd.print(" ");
    }
  }

  delay(2000); // Wait before next reading
}
```

PHYTHON CODING FOR TEMPERATURE READINGS AND HUMIDITY SENSOR READING AND AUTOMATED .CVS FILING

import serial import csv import time import requests from datetime import datetime
=== *CONFIG* ===
arduino_port = 'COM3' # 🛠 Replace with your actual Arduino port if needed baud_rate = 9600 filename = "moisture_temp_log.csv" API_KEY = '16b2757c444b4da4e8f561afa075f604' CITY = 'Las Cruces,US' temperature_fetch_hours = [8, 14, 20] # Fetch temperature at 8 AM, 2 PM, 8 PM
=== *Weather API Function* ===
def fetch_temperature(): try: url = f'https://api.openweathermap.org/data/2.5/weather?q={CITY}&appid={API_KEY}&units=metric' response = requests.get(url) if response.status_code == 200: data = response.json() temperature = round(data['main']['temp'], 1) print(f" 🌡 Las Cruces Temp Fetched: {temperature}°C") return temperature else: print(f" 🌐 API error: {response.status_code}") return "N/A" except Exception as e: print(" 🌐 Weather fetch error:", e) return "N/A"
=== *Connect to Arduino* ===
ser = serial.Serial(arduino_port, baud_rate) time.sleep(2) # Wait for Arduino to reset
=== *Initialize temp value* ===
current_temperature = fetch_temperature() last_checked_hour = datetime.now().hour
=== *Start Logging* ===

```
with open(filename, mode="w", newline="") as file: writer = csv.writer(file)
writer.writerow(["Timestamp", "Soil Moisture (%)", "Las Cruces Temp (°C)"])
print("🌱 Logging started... Press Ctrl+C to stop.\n")

try:
    while True:
        line = ser.readline().decode("utf-8").strip()
        now = datetime.now()
        current_hour = now.hour

        # Check if it's time to fetch temperature again
        if current_hour in temperature_fetch_hours and current_hour != last_checked_hour:
            current_temperature = fetch_temperature()
            last_checked_hour = current_hour

        if "Moisture" in line:
            try:
                moisture = line.split(":")[1].strip().replace("%", "")
                timestamp = now.strftime("%Y-%m-%d %H:%M:%S")
                writer.writerow([timestamp, moisture, current_temperature])
                print(f"💾 {timestamp} | Moisture: {moisture}% | Temp: {current_temperature}°C")
            except Exception as e:
                print("⚠️ Error saving row:", e)

except KeyboardInterrupt:
    print("\n🛑 Logging stopped.")
    ser.close()
```

Appendix E – Photos

Figure 1(Below): Prototype Assembly in its Entirety

Figure 2 (Above): Filter housing with open top for filter maintenance. The top layer of the filter is visible.

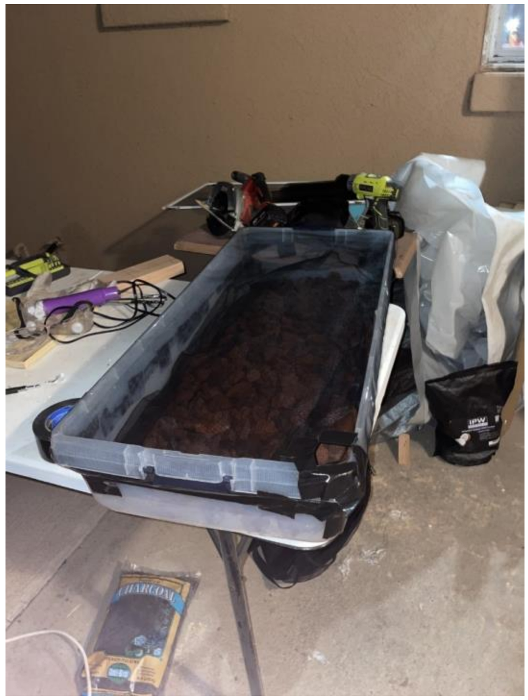

Figure 3 (Above): Close-up of the pre-filter water collection tub

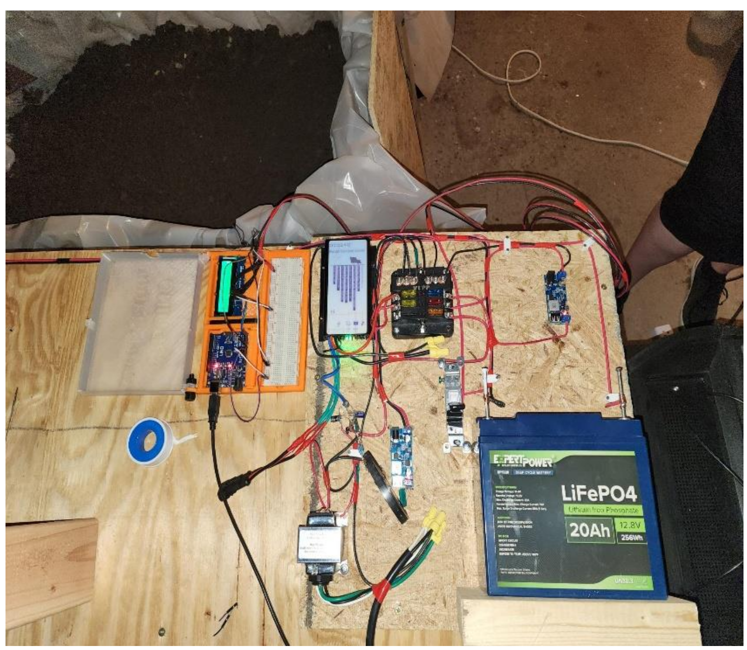

Figure 4: Electronic control panel

Appendix F – MSDS Sheets

MSDS Reference Table

Material	Description	MSDS Link
Activated Charcoal (Carbon)	Used in water filtration	https://www.parchem.com/siteimages/attachment/activated%20carbon%20msds.pdf
Coconut Activated Carbon	Natural charcoal filtration media	https://sds.aquaphoenixsci.com/SDS/180103_Charcoal%20Activated%20Carbon%20%28S25246%29%20_CanadaSDS_English_2018_8_20.pdf
Sand and Gravel	Filtration and drainage layers	https://www.lgeverist.com/safeDatasheets/Sand%20%26%20Gravel%20SDS.pdf
Lava Rock	Drainage and mechanical filtration	https://www.martinmarietta.com/products/safety-data-sheets
Garden Lime (Calcium Carbonate)	pH stabilizer in soil	https://fscimage.fishersci.com/msds/89308.htm
Clay Soil	Soil simulation layer	https://www.missouribotanicalgarden.org/portals/0/Soil_MSDS_Example.pdf
Organic Compost	Nutrient recovery media	https://www.recology.com/wp-content/uploads/2016/01/Compost-Material-Safety-Data-Sheet.pdf
Nitrogen	Soil nutrie	https://www.sigmaaldrich.com/US/en/sds/sial/221244

Fertilizer	nt for testing plant growth	
Herbicide (Glyphosate-based)	Simulated contaminant	https://sds.agrian.com/labelcenter/sds_10743_466.pdf
Cotton	Organic filtration layer	Use general caution; no specific SDS required for untreated cotton

All MSDS were retrieved from official manufacturer and chemical safety sources. Materials were selected based on safety, environmental compatibility, and project effectiveness.

Appendix G – Third-Party Audits (To Be Collected)

ANNE KATHRYN ZIEHE
ESQUIRE*

To: Mrs. Naiqui Armendariz
Mr, Tye Bell
Mr. Roberto Moreno
Mr. Sohan Dissanayake
Mr. Wyatt Ziehe
100 Vista Del Monte Apt Q28A
Las Cruces, NM, 88001

Team 31

To: Team Renewable Energy Solution for Water & Environmental Restoration
From: Hashem Aliedeh, Business Advisor
Subject: Business Feedback – Wildfire Remediation Filtration System
Date: 3/31/2025

Dear Team Renewable Energy Solution for Water & Environmental Restoration

First, I want to commend you on the depth of technical and conceptual work demonstrated in your WERC Capstone project. Your integration of renewable energy, natural filtration media, and sensor monitoring shows real creativity and potential. The feedback I'm offering here is purely recommendatory, intended to help sharpen the business case around your solution and set the stage for commercialization, scaling, or grant-seeking opportunities.

Appendix H- (people involved in the project)

Will your team be bringing a 50-gallon water barrel to the event? EH&S is bringing some 55-gallon barrels for another team and we will include one for your team as well. If you just want to use that barrel for your water supply, you have that option.

We do not allow any water to be drained at F&R. This protects NMSU's reputation and prevents someone from thinking that we are dumping contaminated material. So, during decommissioning, you will need to put all of your water into that EH&S barrel for disposal on campus.

Please let me know the answer to my question and if you have any other concerns.

Please let your team know that your ESP is approved for the WERC Design Contest.

Thank you,
Juanita Miller, PE, CFEI
College of Engineering Safety Specialist
New Mexico State University
miljgh@nmsu.edu
575-415-7999 (cell)