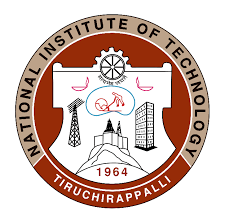
**NATIONAL INSTITUTE OF TECHNOLOGY, TIRUCHIRAPALLI**

**DEPARTMENT OF ENERGY AND ENVIRONMENTAL ENGINEERING**

**TECHNO-ECONOMIC ANALYSIS OF USE OF SOLID ALKALINE FUEL CELL FOR POWERING UP AN OFF-GRID COMMUNITY**



**DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING**

**GROUP NUMBER : 9**

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**1)ABSTRACT**

The transition to sustainable energy sources is a critical challenge, particularly for off-grid communities where reliable electricity is often scarce or non-existent. Solid alkaline fuel cells (SAFCs), known for their high efficiency and ability to utilize renewable energy sources, offer a promising solution to this problem. This study presents a techno-economic analysis to assess the feasibility and economic viability of deploying SAFCs in off-grid communities.

The analysis is based on a comprehensive model that incorporates factors such as energy demand, fuel cell efficiency, system scalability, and cost of installation and maintenance. It also considers various energy sources, including hydrogen produced from renewable sources, and compares the performance of SAFCs at various temperatures (from 60°c to 100°c) and various concentration ranges of KOH (from 25wt% to 30wt%) against traditional photovoltaic cells used to power off-grid communities and concludes the best suitable method for off-grid power generation (among SAFCs and PVs) considering both technical and economic parameters.

Results indicate that SAFCs can provide a reliable and sustainable source of electricity for off-grid communities. The high efficiency of SAFCs and their low emissions profile contribute to a reduced environmental impact compared to conventional power sources. Additionally, SAFCs demonstrate competitive lifetime costs due to their durability and reduced maintenance requirements.

However, the study identifies several challenges, including the initial capital investment, hydrogen production and storage infrastructure, and the need for technical expertise in fuel cell technology. Addressing these challenges through government incentives, community education, and partnership with renewable energy providers can enhance the economic viability and adoption rate of SAFCs in off-grid applications.

The study concludes that, with appropriate support, SAFCs have the potential to revolutionize power generation in off-grid communities, promoting energy independence and sustainability. Further research into optimizing fuel cell technology and reducing costs is recommended to enhance the long-term benefits of this approach.

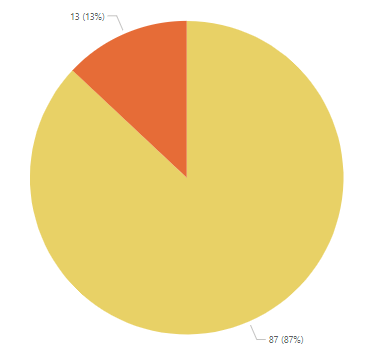
**2) INTRODUCTION**

Off-grid communities in India face a challenging energy scenario marked by limited access to reliable electricity, affecting both their quality of life and economic development. These communities, often located in remote or rural areas, rely on a combination of traditional energy sources such as kerosene lamps, wood-burning stoves, and diesel generators. These sources are not only costly but also contribute to indoor air pollution and greenhouse gas emissions, posing health and environmental risks. The intermittent and unreliable nature of these traditional energy sources also hampers education, healthcare, and business operations in these communities. Recent efforts to improve the energy landscape include the deployment of decentralized renewable energy solutions, such as solar power, micro-hydro systems, and biomass-based energy. However, significant challenges remain, including the high upfront costs of renewable technologies, lack of technical expertise for maintenance, and logistical issues related to transportation and infrastructure. Addressing these challenges requires coordinated efforts from the government, private sector, and non-profit organizations to promote sustainable energy solutions and ensure that off-grid communities in India can access reliable and clean sources of electricity.

**2.1) ENERGY SCENARIO IN OFF-GRID COMMUNITIES:**

In pursuing the United Nations’ Sustainable Development Goal of affordable, reliable, sustainable and modern energy access for all, India’s electrification efforts are dominated by a central electricity grid, with 100% of villages now connected. Despite this, 305 million people still remain without electricity. Off-grid electrification may play an important role in energy access for these ‘last mile’ consumers.

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**2.2) WHAT IS A FUEL CELL:**

Fuel cells are energy conversion devices that generate electricity through an electrochemical process rather than combustion. Unlike traditional power sources, fuel cells operate by combining hydrogen (or other fuels) with oxygen to produce electricity, water, and a small amount of heat. This process is highly efficient and produces significantly lower emissions compared to fossil fuel-based power generation. Fuel cells come in various types, such as proton exchange membrane fuel cells (PEMFCs), solid oxide fuel cells (SOFCs), and alkaline fuel cells, each with unique characteristics and applications. Their versatility allows them to be used in a range of settings, from powering electric vehicles and portable electronics to providing electricity for off-grid communities and backup power systems. The key advantages of fuel cells include their efficiency, quiet operation, scalability, and environmental benefits, making them a promising technology for sustainable energy solutions. However, challenges such as high initial costs, hydrogen production and storage, and infrastructure limitations must be addressed for wider adoption. Despite these challenges, ongoing advancements in fuel cell technology are paving the way for a cleaner and more efficient energy future.

**2.3) CLASSIFICATION OF FUEL CELLS BASED ON ELECTROLYTE:**

|  |  |  |
| --- | --- | --- |
| S No. | FUEL CELL TYPE | ELECTROLYTE USED |
| 1) | Proton Exchange Membrane Fuel Cell (PEMFC) | Nafion (perfluoro-sulfonic acid) membrane |
| 2) | Direct Methanol Fuel Cell (DMFC) | Liquid Methanol |
| 3) | Phosphoric Acid Fuel Cell (PAFC) | Liquid Phosphoric Acid |
| 4) | Molten Carbonate Fuel Cell (MCFC) | Molten Carbonate (Solid) |
| 5) | Solid Oxide Fuel Cell (SOFC) | Yttria-Stabilized Zirconia (YSZ)  (Solid) |
| 6) | **Alkaline Fuel Cell (AFC)** | **Hydroxides of Group 1 or Group 2 metals** |

**2.4) TYPES OF ALKALINE FUEL CELLS:**

* **Liquid Alkaline Fuel Cells (LAFC):** In liquid alkaline fuel cells, the electrolyte is in liquid form, usually a potassium hydroxide solution. These cells operate at relatively low temperatures (around 60-80 degrees Celsius) and are known for their high efficiency. Liquid alkaline fuel cells have been used in space applications, such as in the Apollo spacecraft.
* **Polymer Electrolyte Alkaline Fuel Cells (PEAFC):** Also known as anion exchange membrane fuel cells (AEMFC), these cells use a solid polymer electrolyte membrane instead of a liquid electrolyte. The membrane allows hydroxide ions to pass through while blocking the passage of gases like hydrogen and oxygen. Polymer electrolyte alkaline fuel cells operate at lower temperatures compared to their liquid counterparts and are being researched for various applications.
* **Direct Alkaline Fuel Cells (DAFC):** In a direct alkaline fuel cell, the alkaline electrolyte is in direct contact with the fuel (hydrogen) and oxidant (oxygen) without the need for an additional membrane. This design aims to simplify the cell structure and reduce costs. Direct alkaline fuel cells have the potential for high efficiency, but challenges such as electrode stability and the need for pure hydrogen have to be addressed.
* **Solid Alkaline Fuel Cells (SAFC):** Solid alkaline fuel cells use a solid alkaline electrolyte, eliminating the need for liquid electrolytes. These cells offer the advantage of avoiding issues associated with liquid electrolytes, such as leakage and corrosion. Solid alkaline fuel cells are still in the early stages of research and development.

**2.5) WORKING OF A FUEL CELL:**

A fuel cell generates electricity through an electrochemical process in which hydrogen and oxygen combine to produce water, releasing energy in the form of electricity and heat. At its core, a fuel cell consists of an anode, a cathode, and an electrolyte membrane. The process begins at the anode, where hydrogen gas is split into protons and electrons. The protons pass through the electrolyte membrane to the cathode, while the electrons are directed through an external circuit, creating an electric current that can be used to power devices or machines. At the cathode, the protons, electrons, and oxygen from the air combine to form water, the only byproduct. This process is highly efficient and environmentally friendly, as it produces electricity with minimal emissions and operates without combustion. Fuel cells can be used in a variety of applications, from powering vehicles to providing stationary power for buildings or off-grid communities.

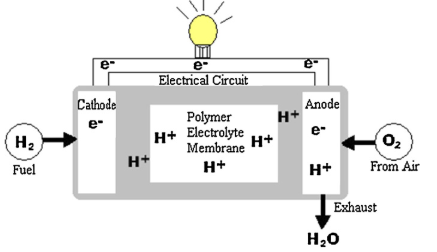


Fig. 1 Pictorial Representation to Explain the Working of Fuel Cell

CELL REACTIONS:

ANODIC HALF CELL REACTION:

2H2 → 4H+ + 4e−

CATHODIC HALF CELL REACTION:

O2 + 4H+ + 4e−  2H2O

NET CELL REACTION:

2H2 + O2 2H2O

**3) ALKALINE FUEL CELLS:**

Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water on-board spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. In recent years, novel AFCs that use a polymer membrane as the electrolyte have been developed. These fuel cells are closely related to conventional PEM fuel cells, except that they use an alkaline membrane instead of an acid membrane. The high performance of AFCs is due to the rate at which electro-chemical reactions take place in the cell. They have also demonstrated efficiencies above 60% in space applications.

A key challenge for this fuel cell type is that it is susceptible to poisoning by carbon dioxide (CO2). In fact, even the small amount of CO2 in the air can dramatically affect cell performance and durability due to carbonate formation. Alkaline cells with liquid electrolytes can be run in a recirculating mode, which allows for electrolyte regeneration to help reduce the effects of carbonate formation in the electrolyte, but the recirculating mode introduces issues with shunt currents. The liquid electrolyte systems also suffer from additional concerns including wettability, increased corrosion, and difficulties handling differential pressures. Alkaline membrane fuel cells (AMFCs) address these concerns and have lower susceptibility to CO2 poisoning than liquid-electrolyte AFCs do. However, CO2 still affects performance, and performance and durability of the AMFCs still lag that of PEMFCs. AMFCs are being considered for applications in the W to kW scale. Challenges for AMFCs include tolerance to carbon dioxide, membrane conductivity and durability, higher temperature operation, water management, power density, and anode electrocatalysis.

**3.1) WORKING OF AN ALKALINE FUEL CELL:**

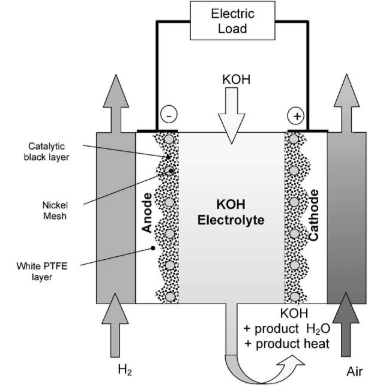
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Fig.2 Pictorial Representation of Working of Alkaline Fuel Cell

CELL REACTIONS:

ANODIC HALF CELL REACTION:

2H2 → 4H+ + 4e−

CATHODIC HALF CELL REACTION:

O2 + 4H+ + 4e−  2H2O

NET CELL REACTION:

2H2 + O2 2H2O

**4) SOLID ALKALINE FUEL CELL:**

Solid alkaline fuel cells (SAFCs) are a type of fuel cell that operates with an alkaline electrolyte, typically in a solid form, rather than in a liquid solution. The basic principle involves the use of an alkaline material, such as potassium hydroxide, embedded in a polymer matrix of Poly-vinyl-alcohol (PVA). SAFCs work by facilitating the movement of hydroxide ions (OH-) from the cathode to the anode. At the anode, hydrogen gas reacts with the hydroxide ions to produce water and release electrons. These electrons flow through an external circuit to the cathode, generating electricity. At the cathode, oxygen from the air combines with the electrons and hydroxide ions to produce additional water, completing the cycle. This type of fuel cell is known for its high efficiency, low operating temperature, and ability to use a variety of hydrogen sources, including ammonia and biogas.

**4.1) ADVANTAGES OF SOLID ALKALINE FUEL CELLS OVER TRADITIONAL ALKALINE FUEL CELLS:**

1. Poisoning of KOH due to oxides of carbon can be avoided. The KOH molecules embedded in PVA’s polymer matrix as dispersed phase does not show tendency to react with CO and CO2.
2. Requirement of fuel of very high grades of purity is reduced.
3. The solid-state nature of SAFCs allows for a more compact and streamlined design. This can lead to lower manufacturing costs and ease of integration into various applications, from portable devices to stationary power systems.
4. SAFCs typically operate at lower temperatures compared to other fuel cells, reducing energy losses and simplifying heat management. This can result in longer life spans and reduced wear and tear on components.

**4.2) PVA-KOH MEMBRANE ELECTROLYTE**

The PVA-KOH membrane, prepared by incorporating potassium hydroxide (KOH) into a polyvinyl alcohol (PVA) matrix, serves as a crucial component in solid alkaline fuel cells (SAFCs). This membrane is typically prepared through a solution casting method, where PVA and KOH are dissolved in water, followed by casting and drying to form a solid, ion-conductive membrane. The PVA-KOH membrane exhibits excellent ionic conductivity due to the high mobility of OH- ions within its structure, crucial for enhancing the fuel cell's efficiency. The transport number for OH- ions in this membrane is notably high, approaching unity, indicating that it predominantly conducts OH- ions over other species like water or cations. This selective transport of hydroxide ions is vital for maintaining high fuel cell performance, enabling efficient electrochemical reactions at the anode and cathode interfaces. The membrane's properties contribute significantly to improving the overall performance and stability of SAFCs, making it a promising material for next-generation alkaline fuel cell technologies.

**5) CALCULATIONS NEEDED FOR TECHNICAL ANALYSIS OF SAFC FOR REMOTE POWER GENERATION:**

**5.1) ELECTROMOTIVE FORCE (EMF):**

* The electromotive force (EMF) of a solid alkaline fuel cell (SAFC) refers to the voltage generated by the fuel cell when no current is drawn from it.
* **THE EMF FOR A TYPICAL SOLID ALKALINE FUEL CELL OPERATING AT ROOM TEMPERATURE IS 1.23V.(STANDARD EMF)**
* The EMF of the SAFC can be determined at any temperature, pressure of hydrogen gas passed as fuel and any composition of PVA-KOH membrane by using Nernst equation.

Net Cell Reaction:

2H2 + 4OH-2H2O

Therefore, the reaction’s activity quotient is given by,

K = (pressure of hydrogen gas)-2(composition of KOH in electrolyte)-4

Generally, in solid alkaline fuel cells, the composition of KOH in electrolyte varies from 25 wt% to 30 wt%. The pressure at which Hydrogen gas is passed into the SAFC varies from 1 atm to 3 atm. The temperature range in which the SAFC is operated is from 60° to100°c.

The EMF Equation is given by,

EMF = 1.23 + (R T / (4 F)) log(k)

Where, R = 8.314 (j/mol k) – Universal gas constant

F = 96485 (c/ mol) – Faraday’s constant

**5.2) POWER OUTPUT:**

Assuming that the current density in the fuel cell is 20 A/m2, the power delivered by the operation of a single solid alkaline fuel cell is given by,

Power output = EMF x Current (Expressed in watt-hours)

**5.3) EFFICIENCY:**

Efficiency of a solid alkaline fuel cell is given by,

η = Standard EMF/ (EMF at any particular temperature and activity)

**5.4) HEATING RATE:**

Heating rate of a solid alkaline fuel cell is given by,

H = power output x (1 – Efficiency) (Expressed in watts)

**6) A PYTHON PROGRAM TO COMPUTE EMF(V), POWER OUTPUT(WH), EFFICIENCY AND HEATING RATE (W) AT VARIOUS TEMPERATURES, COMPOSITION OF KOH AND PRESSURE OF HYDROGEN GAS PASSED AS FUEL**

**6.1) AIM OF THE PROGRAM:**

To compute EMF, Power output, Efficiency and heating rate of the solid alkaline fuel cell at various temperatures, compositions of KOH and pressures of hydrogen gas.

**6.2) PYTHON CONCEPTS USED IN THE PROGRAM:**

1) Functions

2) Python libraries

3) CSV files

4) Python collections (strings, lists, tuples, dictionaries)

**6.3) PYTHON LIBRARIES USED IN THE PROGRAM:**

1. PANDAS
2. NUMPY
3. MATH

**6..4) ALGORITHM OF THE PROGRAM:**

**1)**Initialization:

* Define constants for universal gas constant (R), Faraday's constant (F).
* Define ranges for temperature, KOH percentage, and hydrogen pressure.

2) Function Definitions:

* calculate\_emf(temperature, koh\_percentage, pressure): Calculate the electromotive force (EMF) given temperature, KOH percentage, and hydrogen pressure.
* calculate\_power(emf): Calculate the power output given EMF.
* calculate\_efficiency(emf): Calculate efficiency based on a theoretical ideal EMF.
* calculate\_heat\_dissipation(power\_output, efficiency): Calculate heat dissipation based on power output and efficiency.

3) Data Collection:

* Initialize an empty list to store results.
* Iterate through each combination of temperature, KOH percentage, and hydrogen pressure.

4) Calculate EMF.

5) Calculate power output.

6) Calculate efficiency.

7) Calculate heat dissipation.

8) Store these results in the list as a dictionary.

9) Data Conversion and Storage:

* Convert the collected data into a pandas DataFrame.
* Write the DataFrame to a CSV file named alkaline\_fuel\_cell\_data.csv.

10) Print Message:

* Print a message indicating that the data has been generated and saved to a CSV file.

**6.4) THE PYTHON PROGRAM:**

import pandas as pd

import numpy as np

from math import log

# Constants

R = 8.314  # J/(mol\*K), Universal gas constant

F = 96485  # C/mol, Faraday's constant

# Set up the data ranges for temperature, KOH percentage, and pressure of hydrogen gas

temperature\_range = np.arange(20, 101, 10)  # From 20°C to 100°C in 10-degree steps

koh\_percentage\_range = np.arange(25, 31, 1)  # From 25% to 30% in 1% steps

pressure\_range = np.arange(1, 4, 1)  # From 1 atm to 3 atm in 1 atm steps

# A function to calculate EMF using the given Nernst equation

def calculate\_emf(temperature, koh\_percentage, pressure):

    T\_K = temperature + 273.15  # Convert Celsius to Kelvin

    emf = 1.23 + (R \* T\_K / (4 \* F)) \* log(1/(((koh\_percentage)\*\*( 4)) \* (pressure)\*\*(2)))

    return emf

# A function to calculate power output

# Assume a specific current (in Amperes) and calculate power (P = V \* I)

# For simplicity, assume a constant current of 1 A for 1 hour

def calculate\_power(emf):

    current = 20  # Current in amperes

    time\_in\_hours = 1  # Time in hours

    power\_output = emf \* current \* time\_in\_hours

    return power\_output

# A function to calculate heat dissipation given power output and a fixed efficiency

def calculate\_heat\_dissipation(power\_output, efficiency):

    return power\_output \* (1 - efficiency)

# A function to calculate efficiency (assuming a maximum possible efficiency of some ideal condition)

def calculate\_efficiency(emf):

    ideal\_emf = 1.23  # Theoretical maximum EMF for this type of cell

    efficiency = emf / ideal\_emf

    return efficiency

# Data collection and storage

data = []

# Loop through the various conditions and calculate values

for temperature in temperature\_range:

    for koh\_percentage in koh\_percentage\_range:

        for pressure in pressure\_range:

            # Calculate EMF

            emf = calculate\_emf(temperature, koh\_percentage, pressure)

            # Calculate Power output

            power\_output = calculate\_power(emf)

            # Calculate Efficiency

            efficiency = calculate\_efficiency(emf)

            # Calculate Heat Dissipation

            heat\_dissipation = calculate\_heat\_dissipation(power\_output, efficiency)

            # Collect the data

            data.append({

                "Temperature (°C)": temperature,

                "KOH Percentage (%)": koh\_percentage,

                "Hydrogen Pressure (atm)": pressure,

                "EMF (V)": emf,

                "Power Output (Wh)": power\_output,

                "Efficiency": efficiency,

                "Heat Dissipation (W)": heat\_dissipation

            })

# Convert the data to a DataFrame

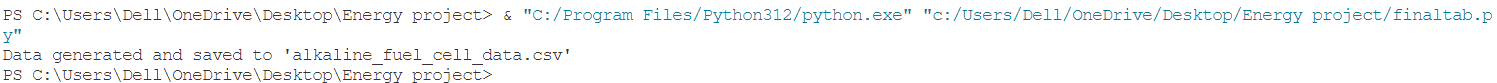
df = pd.DataFrame(data)

# Write the data to a CSV file

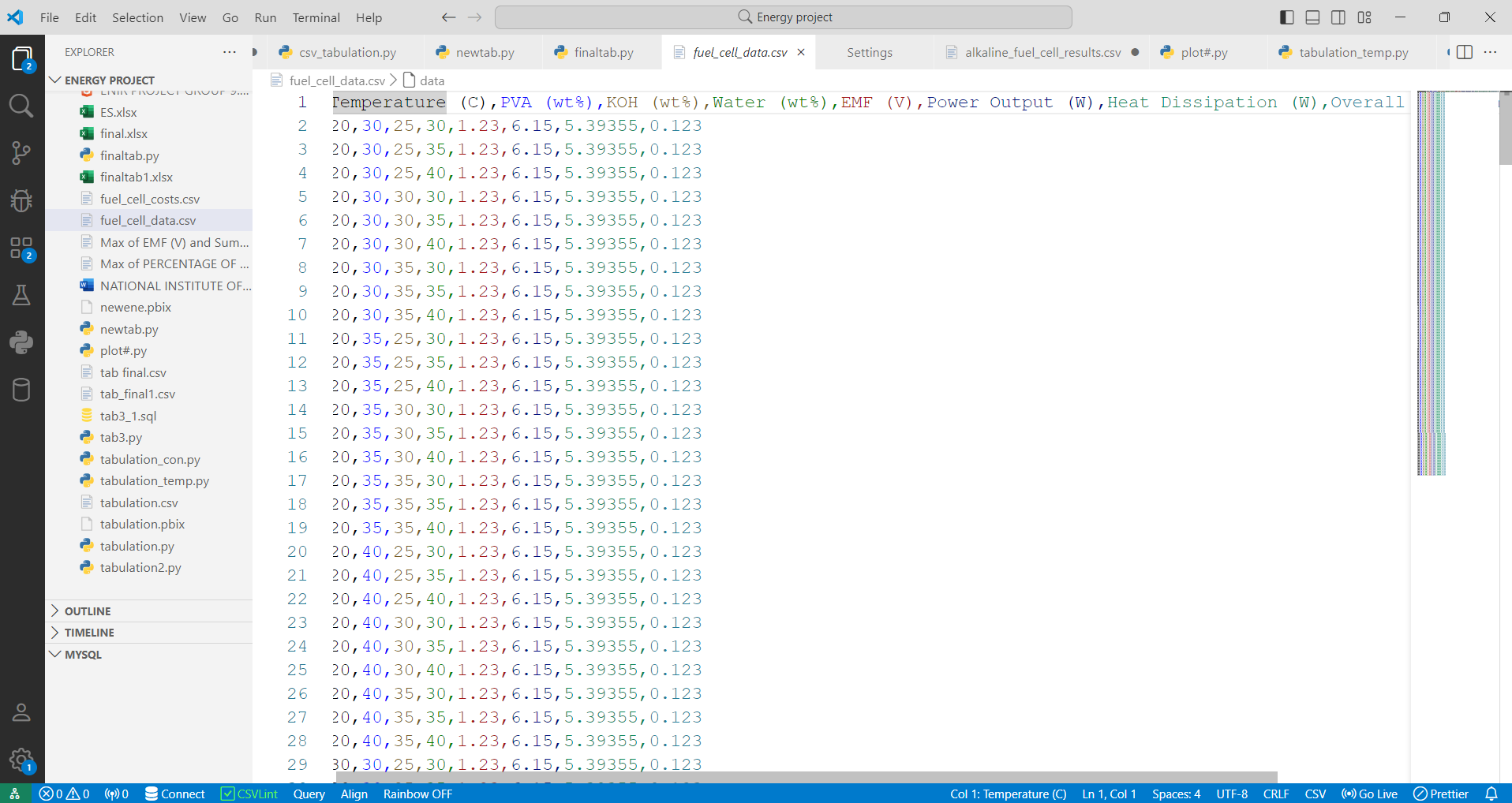
df.to\_csv("alkaline\_fuel\_cell\_data.csv", index=False)

print("Data generated and saved to 'alkaline\_fuel\_cell\_data.csv'")

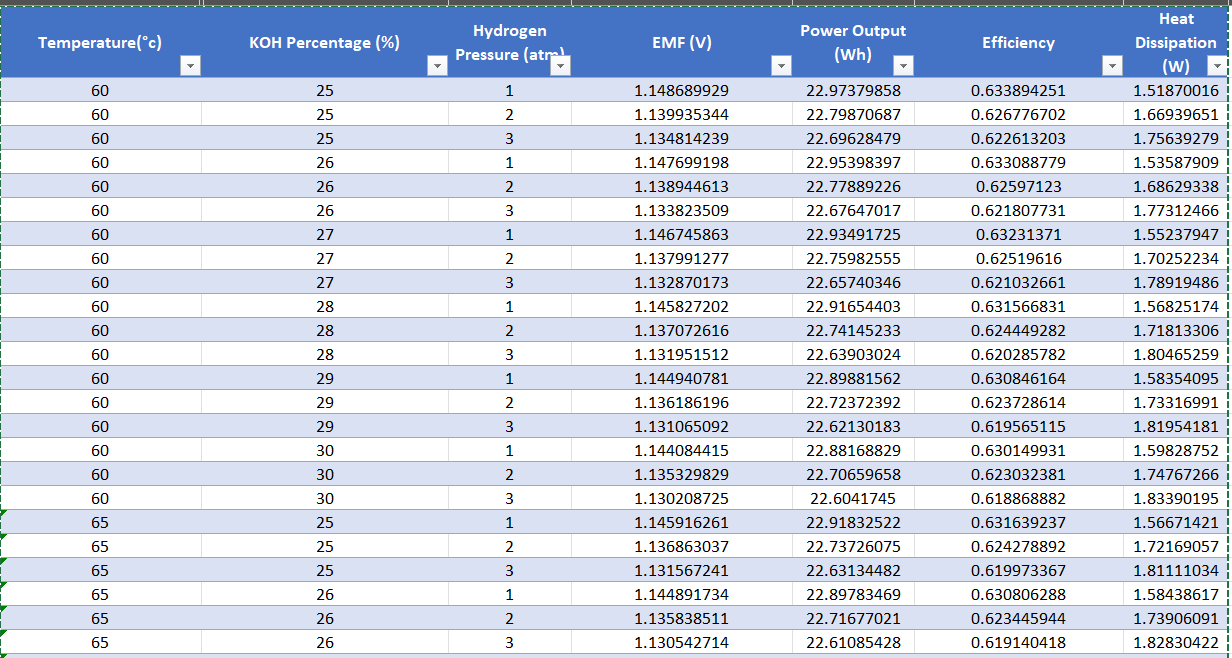
**6.5) OUTPUT OF THE PROGRAM:**

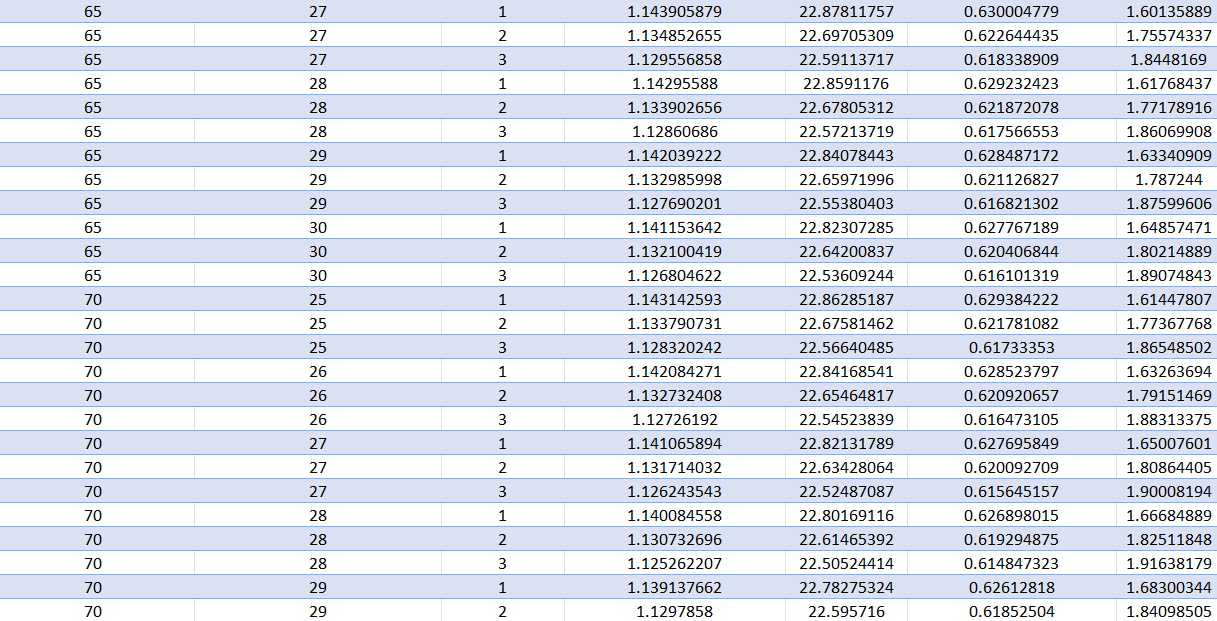
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**6.6) THE CSV FILE:**

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**7) TABULATION OF DATA OBTAINED FROM THE PYTHON PROGRAM:**

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**LINK TO THE EXCEL SPREADSHEET:**

[finaltab1.xlsx](https://1drv.ms/x/c/128b80c78f9a6710/EbvH-75qZupAuArunip1zbMBXXuuw8JE36jN4O0VFlGh1Q?e=jo9pgF)

**8) PLOTTING CURVES FROM THE ABOVE TABULATION:**

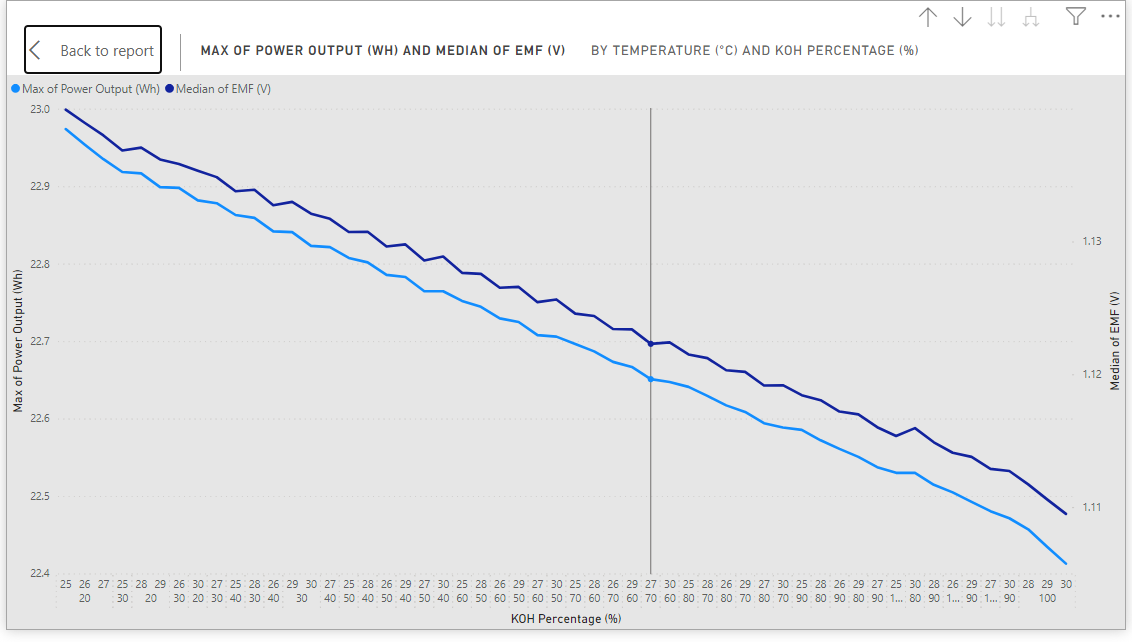


Fig.3 Plot of maximum power output and median EMF vs KOH composition and temperature



Fig.4 Plot of maximum EMF vs Hydrogen gas pressure

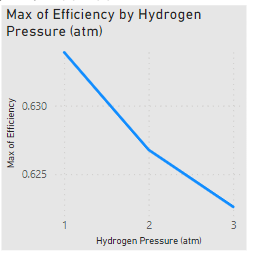
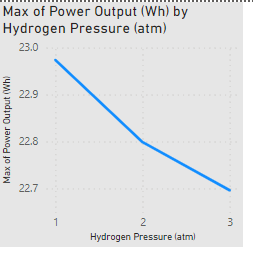
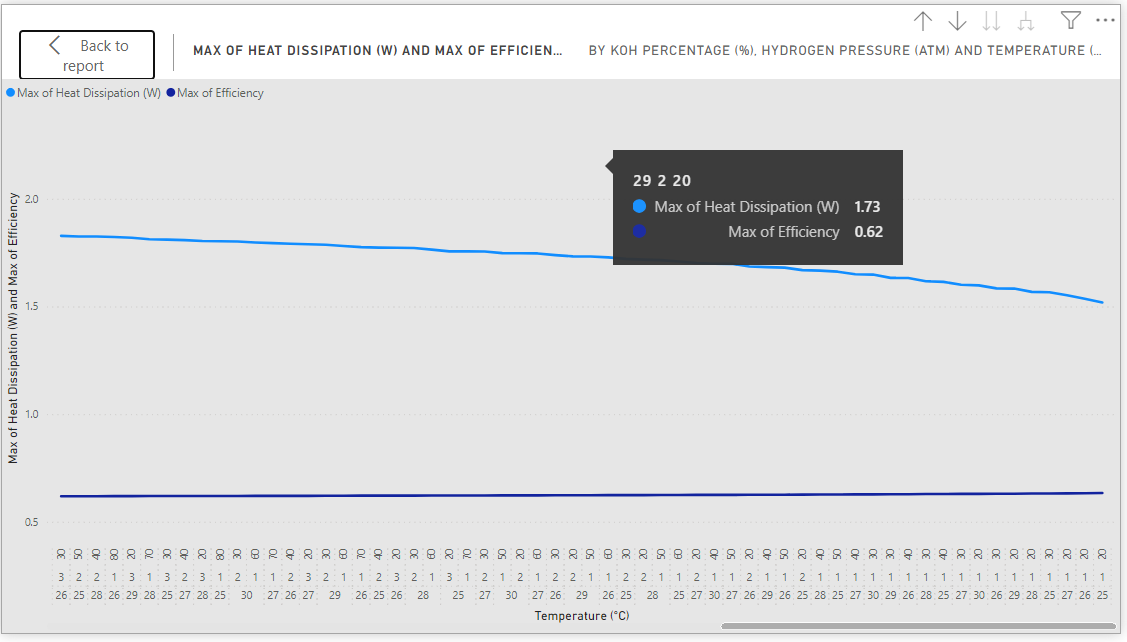
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Fig. 5.1,5.2 Plot of maximum efficiency and maximum power output vs Hydrogen

Gas pressure

****

Plot of maximum heat dissipation and maximum efficiency vs Temperature, composition of KOH and Pressure of Hydrogen gas

**Tools used for analyzing the data acquired from the python program:**

1. **Microsoft Excel**
2. **Microsoft PowerBI**

**9) ECONOMIC ANALYSIS:**

Table below contains the capital costs of various equipment as well as other key data for economic analysis. The total capital cost (CAPEX) is the summation of all the components of the system, and it is estimated as follows:

CAPEX = ∑ i CAPi

where, CAPi is the capital cost of ith component

|  |  |
| --- | --- |
| COMPONENT(i) | COST(CAPi) in INR |
| H2 fuel | 450/kg |
| O2 oxidant | 1800 for 300L cylinder |
| Pt catalyst | 320/gm |
| KOH electrolyte | 25/kg |
| PVA membrane | 65/kg |
| Silver-Palladium electrode | 3500/piece |
| Nickel-Chromium electrode | 2500/kg |
| Pump + Compressor + Heat Exchanger + Pipe works | 15000/kw |
| Heat Network | 62500/MWh |
| Electricity selling cost | 16.5/kWh |

The discount rate is considered to be 3% , and its lifespan is 30 years. The cost of yearly operation and maintenance is anticipated to be 2.5% of CAPEX. The system needs periodic replacements of SAFC and other components. The annual replacement costs have been projected to be 5% of CAPEX. The total annual cost of the system is the combination of the annual capital cost, annual operational and maintenance cost, annual replacement cost, and annual fuel cost, as shown in the following equation.

COST(Annual) = CAPEX(Annual) + OPEX(Annual) + REP(Annual) + FUEL(Annual)

The levelized cost of energy (LCOE) of the system can be determined by the following equation:

LCOE = COST(Annual)/ Total Energy Production

where unit of COST(Annual) is INR and unit of ’Total Energy Production’ is kWh.

CAP : Individual component cost

CAPX : Total capital cost

FUEL : Total fuel cost

LCOE : Levelized cost of energy

OPEX : Total operational cost

REP : Total replacement cost

Previously it was explained the general economic distribution of a solid alkaline fuel cell (SAFC) . Now let’s consider its utilization in our primary application i.e. powering off-grid stations.

Consider a hypothetical off-grid system with 100 household settlement and prospects of more industries to set up in future. On average, each household will require 70-75 Watts of electricity per hour. Now, an SAFC has a power output of 23Wh. So, we would be needing a stack of 3-4 SAFCs to power 1 household for 1 hour. Likewise, we would require a stack of approximately 315 fuel cells to power the entire settlement for 1 hour.

**10) SPECIFICATIONS OF PHOTOVOLTAIC CELLS USED FOR POWERING UP AN OFF-GRID COMMUNITY**

* The maximum efficiency a photovoltaic cell (silicon based) can achieve is 0.25.
* The performance of the cell heavily relies on environmental conditions like,

**Temperature**: PV cells can lose efficiency as they heat up. High temperatures can reduce the efficiency of silicon-based PV cells.

**Angle and Orientation**: The angle at which sunlight strikes the PV cells can affect efficiency. Optimal orientation and tilt angle can maximize energy capture.

**Dust and Dirt**: Accumulation of dust, dirt, or debris on the panels can decrease efficiency.

**Age and Degradation**: PV cells can degrade over time, leading to a gradual reduction in efficiency.

**10.1) ECONOMIC ESTIMATE TO POWER THE OFF-GRID COMMUNITY BY PHOTOVOLTAIC CELLS:**

Energy demand per household = 50 kWh per month.

Number of households = 100.

Total monthly energy demand = 50 kWh × 100 = 5,000 kWh.

Since solar systems produce energy during daylight hours, it's helpful to convert the monthly demand into daily demand to better estimate the system size:

Total daily energy demand = 5,000 kWh ÷ 30 days = 166.67 kWh (rounded to two decimal places).

Peak Sun Hours: The number of hours of effective sunlight in a day. In India, this typically ranges from 4 to 6 hours, depending on location and season.

PV System Efficiency: Generally, a system operates at around 80% efficiency due to various losses (e.g., inverter losses, temperature effects).

With these assumptions, we can estimate the required system capacity to meet the daily energy demand. Using 5 peak sun hours and 80% efficiency, the total system capacity can be calculated as follows:

Required system capacity = (166.67 kWh ÷ 5 peak sun hours) ÷ 0.8 = 41.67 kW.

Rounding this up, a 42 kW solar system is required to meet the daily energy demand for this community.

In India, the cost of solar systems typically ranges from ₹20,000 to ₹35,000 per kilowatt-peak (kWp). Using this range, we can estimate the cost of a 42 kW solar system:

Low-end estimate: 42 kW × ₹20,000 = ₹840,000.

High-end estimate: 42 kW × ₹35,000 = ₹1,470,000.

Battery Storage: To store energy for nighttime or cloudy days, batteries are needed. Battery costs can range from ₹10,000 to ₹30,000 per kWh. To estimate battery capacity, assume a backup storage equivalent to a full day's energy demand (166.67 kWh).

Low-end battery cost: 166.67 kWh × ₹10,000 = ₹1,666,700.

High-end battery cost: 166.67 kWh × ₹30,000 = ₹4,999,700.

Installation and Labor: Typically 10% to 20% of the total equipment cost.

Combining these costs, the total cost estimate can range widely, depending on the choices made for battery storage, installation, and other components. Adding together the estimated solar system cost and battery storage:

Low-end total estimate: ₹840,000 (PV) + ₹1,666,700 (batteries) ≈ ₹2,506,700.

High-end total estimate: ₹1,470,000 (PV) + ₹4,999,700 (batteries) ≈ ₹6,469,700.

**10.2) ECONOMIC ESTIMATE TO POWER THE OFF-GRID COMMUNITY BY SAFC:**

The costs for SAFC systems can vary based on capacity, design, and hydrogen infrastructure. Here's an estimate based on typical costs in India and other factors:

Fuel Cell System:

* The cost for solid alkaline fuel cells typically ranges from ₹50,000 to ₹200,000 per kilowatt (kW), depending on the design and technology. Assuming a 20 kW system, the cost estimate is:
* Low-end estimate: 20 kW × ₹50,000 = ₹1,000,000.
* High-end estimate: 20 kW × ₹200,000 = ₹4,000,000.

Hydrogen Storage and Infrastructure:

* Hydrogen storage is a significant cost factor, requiring safe tanks and handling. This could add from ₹10,000 to ₹30,000 per kilogram of storage capacity. Assuming a storage capacity of 100 kg (to accommodate fluctuations and continuous use):
* Low-end estimate: 100 kg × ₹10,000 = ₹1,000,000.
* High-end estimate: 100 kg × ₹30,000 = ₹3,000,000.

Installation and Labor:

* Installation costs typically account for 10% to 20% of the total equipment cost.

Total Cost Estimate

Combining the estimated fuel cell system cost, hydrogen storage, and infrastructure:

Low-end total estimate: ₹1,000,000 (SAFC) + ₹1,000,000 (storage) ≈ ₹2,000,000.

High-end total estimate: ₹4,000,000 (SAFC) + ₹3,000,000 (storage) ≈ ₹7,000,000.

**11)COMPARISON:**

To compare photovoltaic (PV) cells and solid alkaline fuel cells (SAFCs) for powering an off-grid community with 100 households, each with a 50 kWh monthly energy demand, let's consider several factors, including cost, reliability, environmental impact, energy efficiency, and infrastructure requirements.

**Cost Comparison**:

PV Cells: The estimated cost for powering the community with PV cells ranged from ₹2,500,000 to ₹6,500,000, with the cost variation mainly due to battery storage capacity and system size.

SAFCs: The estimated cost for powering the community with SAFCs ranged from ₹2,000,000 to ₹7,000,000, depending on fuel cell capacity, hydrogen storage, and infrastructure.

In terms of cost, both options have a wide range of estimates, with overlap between the low and high ends. The exact costs depend on system specifications and additional infrastructure.

**Reliability and Continuity of Power**:

PV Cells: Solar energy is intermittent, requiring sufficient battery storage to maintain power at night or during cloudy weather. This necessitates careful planning and can increase costs.

SAFCs: Fuel cells provide continuous power as long as hydrogen is available, making them more reliable for off-grid applications. However, this reliability comes with additional infrastructure for hydrogen production, storage, and safety.

SAFCs offer greater reliability due to continuous power generation, whereas PV systems rely heavily on weather conditions and energy storage.

**Environmental Impact :**

PV Cells: Solar energy is renewable and has low operational emissions, but manufacturing and disposal of panels can have environmental impacts.

SAFCs: While SAFCs can be efficient, they rely on hydrogen, which must be produced. If hydrogen is derived from renewable sources, the environmental impact is low; however, if it comes from fossil fuels, it can be high. Proper handling and safety measures are also required.

PV cells generally have a lower environmental impact in terms of emissions, though SAFCs can be eco-friendly when using green hydrogen.

**Infrastructure Requirements:**

PV Cells: Require solar panels, inverters, charge controllers, and significant battery storage. Installation is straightforward but needs periodic maintenance and system checks.

SAFCs: Require fuel cells, hydrogen production, storage, and safety equipment. Installation and handling require more specialized expertise due to the risks associated with hydrogen.

PV systems are generally easier to install and maintain, while SAFCs need specialized infrastructure and technical expertise.

**12) CONCLUSION:**

Given these factors, the most suitable solution for powering the off-grid community depends on specific priorities:

**If Cost and Simplicity Are Prioritized**: PV cells are typically a more straightforward and cost-effective solution, especially with lower upfront costs and easier installation.

**If Reliability and Continuous Power Are Critical**: SAFCs offer a more reliable power source, especially in areas with limited sunlight or challenging weather conditions. However, this comes with additional costs and infrastructure requirements.

In summary, if the off-grid community is in an area with ample sunlight and can accommodate energy storage, PV cells are likely the most suitable and cost-effective solution. However, if reliability and continuous power are more important, and there is a reliable source of hydrogen, SAFCs might be the better choice, despite the additional infrastructure and costs.

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