Detailed cost analysis of Operating expenditures for Recycling 50 tonnes of solar waste

The main operating costs of this process may be divided into two categories:

A) Electricity required
B) Costs of operating materials required

A) First, we will predict the cost of electricity required to run the plant, if the electricity required is less than what the turbine can produce, then the plant will be self-sufficient in its electricity cost-

Electricity will be required mainly in the following processes-

1. Heating of Solar panels to detach Aluminium frames
2. Maintaining the subcritical condition of water
3. Crushers
4. Cutters
5. For plasma pyrolysis (Vapourisation and then condensation)

1. Heating of solar panels to detach aluminium frames:

- Total mass of solar panel waste: 50 tonnes = 50,000 kg.
- Temperature change (ΔT):
  - From 25°C to 200°C: $\Delta T = 200 - 25 = 175$°C
- Heating duration: **10 minutes = 600 seconds**.
- Composition of the waste:
  - **Glass**: 76%
  - **Aluminium**: 8%
  - **EVA (Ethylene Vinyl Acetate)**: 8%
  - **Silicon**: 4%
  - **PVF (Polyvinyl Fluoride)**: 2%
  - **Copper**: 1%

- **Other metals**: 1%.

Specific Heat Capacities (approximate values):

- Glass: **840 J/kg°C**
- Aluminum: **900 J/kg°C**
- EVA: **2090 J/kg°C**
- Silicon: **700 J/kg°C**
- PVF: **1000 J/kg°C**
- Copper: **385 J/kg°C**
- Other metals: **500 J/kg°C** (assumed average for mixed metals)

Mass Calculation:

Each material's mass is calculated by multiplying the total waste mass with its composition fraction:

- Glass: 50,000×0.76 = 38,000 kg
- Aluminium: 50,000×0.08 = 4,000 kg
- EVA: 50,000×0.08 = 4,000 kg
- Silicon: 50,000×0.04 = 2,000 kg
- PVF: 50,000×0.02 = 1,000 kg
- Copper: 50,000×0.01 = 500 kg
- Other metals: 50,000×0.01 = 500 kg

Energy Required:

The energy required to heat each material is calculated using:

$Q=m*c*\Delta T$
Where:

- m is the mass,
- c is the specific heat capacity,
- $\Delta T=175°C$

Energy by Material:

- Glass: Q = 38,000 × 840 × 175 = 5,586,000,000 J
- Aluminum: Q = 4,000 × 900 × 175 = 630,000,000 J
- EVA: Q = 4,000 × 2090 × 175 = 1,463,000,000 J
- Silicon: Q = 2,000 × 700 × 175 = 245,000,000 J
- PVF: Q =1,000 × 1000 × 175 = 175,000,000 J
- Copper: Q = 500 × 385 × 175 = 33,687,500 J
- Other metals: Q = 500 × 500 × 175 = 43,750,000 J

Total Energy Required:

Adding the individual energies:

Q_{total} = 5,586,000,000 + 630,000,000 + 1,463,000,000 + 245,000,000 + 175,000,000 + 33,687,500 + 43,750,000 = 8,176,437,500 J **(≈8.18 GJ)**

The electricity required can be estimated based on the energy consumption calculated above considering the efficiency of the system.

Efficiency of the Heating System:

- Assume a typical industrial heating efficiency of 80% (can vary depending on the setup).
- Effective energy delivered to the system is only 80% of the input electricity.

Electricity Required:

The electricity required can be calculated as:

$E_{input} = Q_{total}/\text{Efficiency}$

Where:

- Q_{total} = 8.18 GJ = 8,176,437,500 J
- Efficiency = 0.8

E_{input} = 8,176,437,500 / 0.8=10,220,546,875 J (≈10.22 GJ)

Convert to kWh:

To express the electricity required in kilowatt-hours

1 kWh = 3.6×10^6 J
(10,220,546,875 / 3.6×10^6 ≈ **2,839.04 kWh**

The electricity required to heat the 50-tonne solar panel waste to 200°C for 10 minutes is approximately 2,839 kWh, assuming 80% heating efficiency.

2. **Maintaining the subcritical condition of distilled water:**

Given Parameters:

1. Cylinder dimensions:
   - Radius (r) = 2 m
   - Height (h) = 7 m

2. Surface Area (A):
   $A = 2\pi rh + 2\pi r^2$
   Substituting the values:
   $A=2\pi(2)(7)+2\pi(2)^2$
3. $A=2\pi(14)+2\pi(4)=28\pi+8\pi=36\pi\approx113.1\ m^2$
4. Temperature Difference (ΔT):
   $\Delta T = 150-25 = 125\ °C$

5. Heat Transfer Coefficient (U):
   - For a moderately insulated system, $U=10\ W/m^2 °C$
6. Time (t):
   - 1 hour=3600 seconds

Step 1: Heat Loss

$Q_{loss}=U\cdot A\cdot\Delta T\cdot t$

Substitute the values:

$Ql_{oss}=10*113.1*125*3600$
$Ql_{oss}=5{,}091{,}000{,}000\ J=5{,}091\ MJ$

Step 2: Electricity Input

Assuming heating efficiency of 80%

$E_{input}=Q_{loss}/Efficiency = 5{,}091\ MJ/0.8$
$E_{input} = 6{,}363.75\ MJ.$

Convert to kWh

E_{input} (kWh) = 6,363.753.6 ≈ **1,767.7 kWh**

The electricity required to maintain the temperature of 400 liters of water at 150°C and 200 atm for 1 hour, using a cylindrical vessel with r=2 and h=7 is approximately 1,767.7 kWh.

3. Crushers:

We have assumed the power of cutters to be 50KW. So if the cutter operates for 8 hours, and their are 9 cutters, so total energy consumption is **50KW*8*9 = 3600KWh**

4. Cutters :

We have assumed that cutters have capacity of 30KW and total 4 cutters are there, considering running time of 8 hours, so total energy consumption is **30*4*8 = 960KWh**

5. For plasma pyrolysis:

The total energy required for complete plasma pyrolysis is 39 GJ, reference being taken from- Energetic analysis[1].docx

So converted into KWh this converts to **$39*10^9/3.6*10^6$ = 10833KWh (1KWh = $3.6*10^6$J)**

So total electricity requirements of plant is (10833+960+3600+1767.7+2839.04) = 20049KWh

Now the energy released by combustion of hydrocarbons (namely ethylene and acetic acid) captured after subcritical treatment with water is 167GJ, this heat is used to heat up the water jet which runs the blade of turbine,

Assuming that 20% of heat is lost during heating up of water = Heat remained is 133.6 KWh.

Assume now assuming efficiency of turbine to be 50%, total electricity generated by turbine is 133.6 *0.5KWh , almost around 66GJ.

In KWh, this turns out to be $66*10^9/3.6*10^6$ = 18333KWh

Now when this electricity runs through electrical systems, there will be losses due to resistance of the system, considering this losses to be 20%.

Finally, the actual electricity in usable form from turbine = 14666 kwh

So we have deficit of almost 6000-7000KWh of electricity, considering the rate of as 8 rupees per Kwh, cost of electricity is 7000*8 = 56000 rupees.

B) Cost of operating materials required

a) **Distilled Water is required for subcritical treatment**

Now, the water under subcritical conditions will basically react only with EVA and PVF and not with metals - [Hydrothermal treatment of solar panels]

Now, EVA is a copolymer of ethylene(C2H4) and vinyl acetate(C2H6O2). The percent composition of ethylene and vinyl acetate in EVA varies between 70-90% and 30-10%. For our case, we have assumed that the composition is 80% and 20% respectively.

Now, the reaction between subcritical water and EVA proceeds as follows-

$(C_2H_4)_n(C_4H_6O_2)_m + m\ H_2O \rightarrow (C_2H_4)_n(C_2H_4)_m + (CH_3COOH)_m$

We can basically say that one mole of water reacts with one mole of vinyl acetate and ethylene chain is retained as it is -

The reference for the above reaction has been taken from - [Subcritical treatment of solar panels]

Now for 50 tonne of waste - 8% is EVA, so EVA is 4000Kg, now
80% * 4000 = 3200 Kg is Ethylene and 20% * 4000 = 800 Kg is vinyl acetate.

Moles of Vinyl Acetate = Mass / Molecular weight
Moles = 80000 / 86
Moles = 931, **So moles of water needed = 931**

In subcritical conditions of water, temperature ranges from 100 to 374 degree celsius and pressure ranges from 0.1MPa to 22MPa.
We have assumed T = 150°C (473K) and P=20MPa (200 atm)

So , PV=nRT
Putting R = 0.0821atmL/molK
P = 200
N = 931
T = 473
V = 161 litres

Now, this is the volume of water required to react with Vinyl acetate. Now water may also react with PVF backsheet (Tedlar - Polyvinyl Fluoride) as well and considering wastage as well, we consider

Volume of water required = 500-1000 litres
Average price of Industrial distilled water = 50/Lit

Total price for water = 50000 rupees

b) Argon gas required for plasma pyrolysis

Based on our calculations from the report - Energetic analysis[1].docx

Maximum moles of Argon (Ar): 87

Volume Calculation (using Ideal Gas Law):
PV=nRT

Substituting values:
V=nRT/ P = 87×0.0821×298/ 1 ≈ 2128 liters

Maximum Volume of Argon required : 2128 liters

1 Argon cylinder has 7 cubic meters.

Cost = **₹2100–₹3500** (Industrial Grade Argon, 99.9% Purity)

Assuming that 1 cylinder is used along:

2128 Lit → **2.128 m³**

So we need to buy 1 cylinder.

Cost of argon = ₹3500

c) Also water jet needed for steam creation from heat generated by combustion.

Heat generated → ~165 GJ
(Reference from our report - Energy Analysis)

To cal amount of H_2O that can be converted to steam using this much heat,

$Q = m \times L$

(Latent heat of vaporization of water)

$L \sim 22.60$ kJ/kg

$165 \text{ GJ} = 165 \times 10^6 \text{ J} = 165 \times 22.60 \times \text{kJ/kg}$

$m = 7300885.4$ kg

Volume of water required:
($\rho = 1000$ kg/m³)

$V = m / \rho = 7300885.4 / 1000 = 7300.9 \text{ m}^3 = 73\text{MLit}$

Cost = 10 Lakh

Total Cost = 10 Lakh + 3500 + 56000 + 50000
= Around 11,10,000